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16. Abstract

This guide provides guidance for the design of horizontal curves on new highway sections and for the reconstruction and upgrading of existing curves on two-lane rural roads. Information is also provided in this guide for computing the expected benefits and costs for a variety of curve improvements, such as curve flattening, roadway widening, providing spiral transitions to curves, improving superelevation, sideslope flattening, and other roadside improvements. Thus, this guide should be useful to highway designers and safety officials responsible for the design of 3R projects, improvements to high-hazard locations, and highway reconstruction as it relates to horizontal curves.

The accident relationships and basic project cost data contained in this guide resulted from research conducted for the Federal Highway Administration. FHWA research report FHWA-RD-90-021 entitled, "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves, Volume I, Final Report" contains the major results and conclusions of the study.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

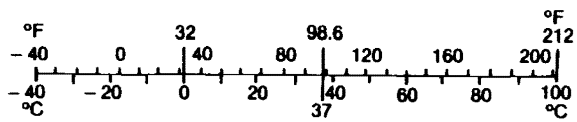
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimetres | mm |
| ft | feet | 0.305 | metres | m |
| yd | yards | 0.914 | metres | m |
| mi | miles | 1.61 | kilometres | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimetres squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | metres squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | metres squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometres squared | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | millilitres | mL |
| gal | gallons | 3.785 | litres | L |
| $ft^3$ | cubic feet | 0.028 | metres cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | metres cubed | $m^3$ |

NOTE: Volumes greater than 1000 L shall be shown in $m^3$.

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 | Celcius temperature | °C |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimetres | 0.039 | inches | in |
| m | metres | 3.28 | feet | ft |
| m | metres | 1.09 | yards | yd |
| km | kilometres | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimetres squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | metres squared | 10.764 | square feet | $ft^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometres squared | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | millilitres | 0.034 | fluid ounces | fl oz |
| L | litres | 0.264 | gallons | gal |
| $m^3$ | metres cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | metres cubed | 1.308 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celcius temperature | 1.8C + 32 | Fahrenheit temperature | °F |




* SI is the symbol for the International System of Measurement

(Revised April 1989)

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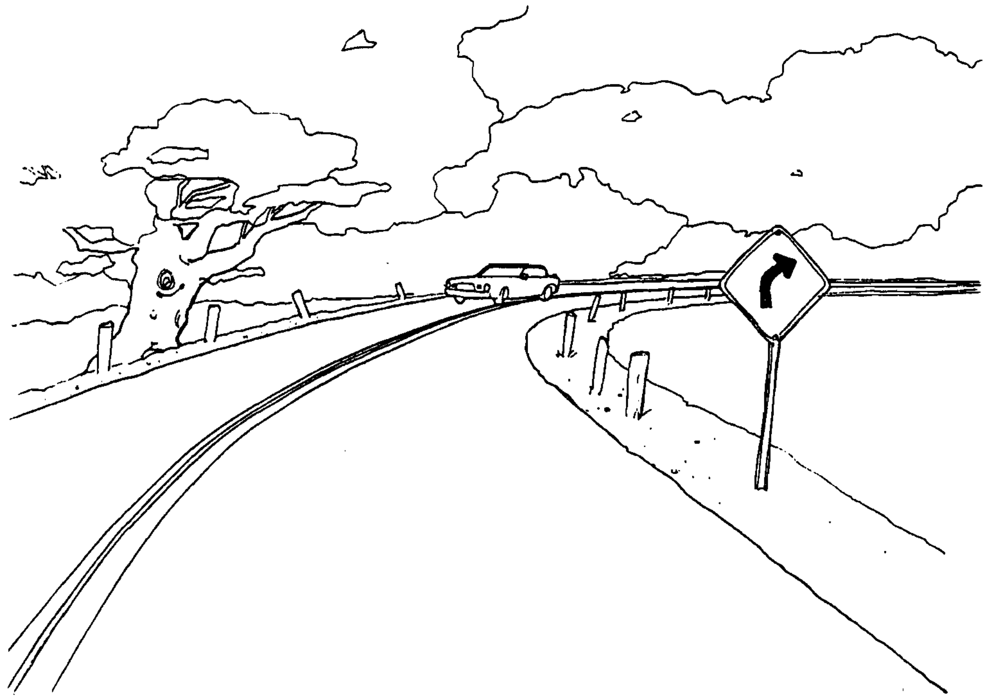
# CHAPTER 1 - INTRODUCTION



Horizontal curves represent a considerable safety problem on rural two-lane roads. One 1980 FHWA study estimated that there are more than 10 million curves on the two-lane highway system in the U.S.[1] Accident studies indicate that curves experience a higher accident rate than tangents, with rates ranging from one and a half to four times higher than similar tangents.[2,3] Also, due to the greater incidence of run-off-road and head-on accidents on curves, accidents are more likely to result in death or serious injury on curves than on tangents.[2]

While accidents on horizontal curves have been recognized as a problem for many years, the issue may perhaps be more important in light of improvements being made as a part of resurfacing, restoration, and rehabilitation, commonly called the 3R program. Because the road surface must be periodically repaved to protect the underlying roadbed structure, a critical issue involves what else should be done at horizontal curves to enhance (or at least hold constant) the level of safety. In addition, the treatment of high-accident locations and major roadway reconstruction efforts often relate to horizontal curves and associated safety problems.

Efforts to reduce accidents on horizontal curves have been severely hampered by limited funding combined with the high cost for curve-related improvements. Also, until recently, the relative safety benefits for various curve improvements was unknown for a given set of traffic and roadway conditions. Thus, the most cost-effective improvement for a given curve site was difficult to identify. This has often led to the selection of low-cost treatments on curves, which in many cases offer no permanent solution to a serious safety problem.

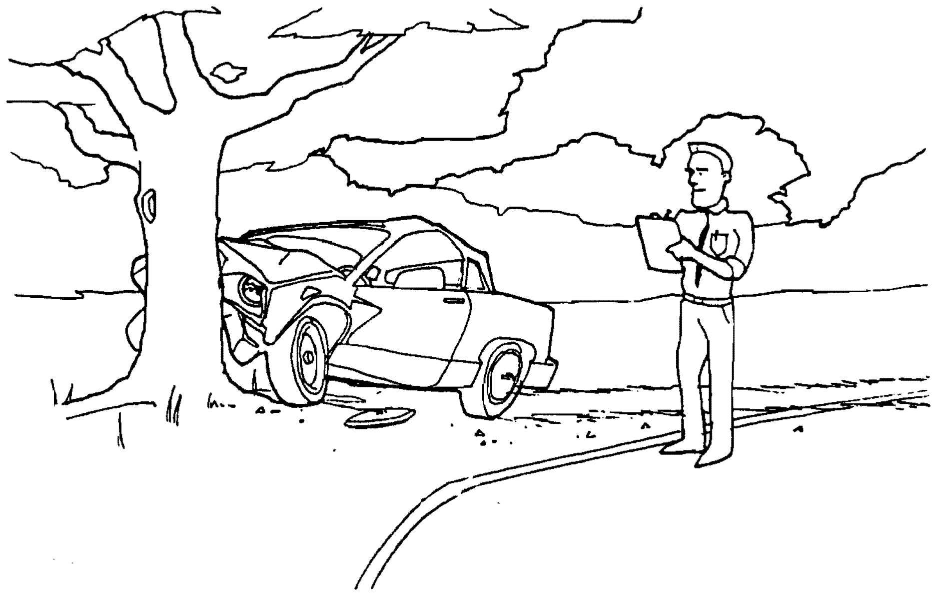
Recent research efforts for FHWA have provided considerable insights into the safety effects of various safety improvements on horizontal curves.(2,3) This guide is based primarily on the results of those recent studies. It provides guidance for the design of new horizontal curves and for the reconstruction and upgrading of existing curves on two-lane roads.

This guide should be useful to highway designers and safety officials responsible for the design of 3R projects, improvement of high-hazard locations, and highway reconstruction as it relates to horizontal curves. Information is also provided in this guide for computing the expected benefits and costs for a variety of curve improvements. Such improvements include:

- Curve flattening.
- Roadway widening.
- Providing spiral transitions to curves.
- Improving superelevation.
- Sideslope flattening.
- Improvements related to roadside obstacles.

Chapter 2 gives definitions of key terms, assumptions for the cost-effectiveness procedure, and relationships among curve features. Chapter 3 provides general guidance on the design of new curves and on upgrading existing curves. The accident effects of specific curve improvements are given in chapter 4, while chapter 5 contains a procedure for estimating costs for curve improvement projects. Using these costs and expected benefits, an economic analysis procedure for project alternatives is given in chapter 6. A case study is included in chapter 7 which applies the procedures in the guide in the selection of optimal curve improvements. All procedures in this guide take into account both isolated curves and non-isolated curves on two-lane rural roads.

# CHAPTER 2 - PROCEDURE INPUTS AND ASSUMPTIONS



The procedures described in the following chapters are designed to evaluate the costs and benefits of various curve-related improvements on two-lane rural roads. The methodology requires that certain types of information is known for each curve relative to physical site features and countermeasure alternatives. This chapter provides details for the following:

- Definitions of key terms (as used in this study).
- Procedure assumptions.
- Relationships of curve features.

## Definitions of Key Terms

Degree of Curve (D) - The sharpness of the curve. It is expressed in terms of angle or number of degrees of circular curve per 100 ft of arc. The degree of curve is directly related to the curve radius, R (in ft), namely,

$$D = \frac{5{,}729.6}{R}$$

Curve Length (L) - The distance, expressed in mi or ft, from the beginning of the curve (termed the Point of Curve, or PC) to the end of the curve (termed the Point of Tangent or PT), as measured along the centerline of the road.

Central Angle (I) - The total angle taken up by the horizontal curve, that is, the angle which would be formed by extending the tangents on either end of the curve, as illustrated in figure 1 below.

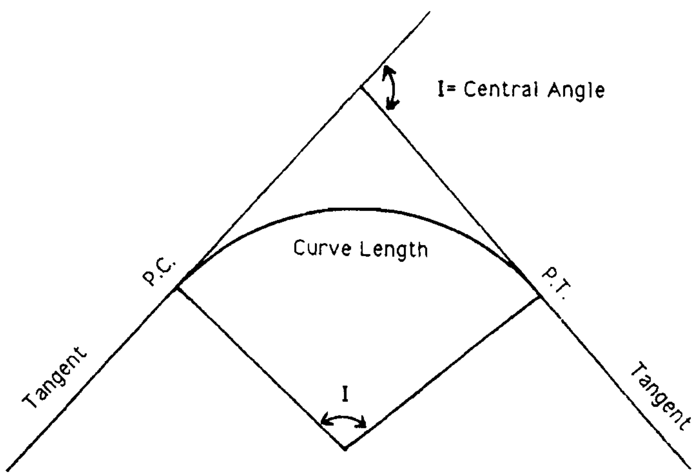



Figure 1. Illustration of horizontal curve features.

Superelevation (e) - The amount of "banking" of the curve, or more specifically the ratio of the difference in elevation on the outside of the curve compared to the inside of the curve divided by the road width. It is measured in ft per ft, since it represents ft of elevation difference per ft of width. For example, a 1-ft increase in elevation on the outside of the curve (compared to the inside of the curve) over a 24-ft wide roadway would correspond to a superelevation of (1 ft) ÷ (24 ft) = .042.

AASHTO Superelevation Criterion - Criterion for the amount of superelevation appropriate for a given curve provided in the AASHTO Greenbook based on:[4]

- An agency's maximum superelevation policy, $e_{max}$ (.06, .08, or .10).
- The design speed of the roadway.
- The degree of curve or radius of curve.

Superelevation Deviation - The superelevation deviation (sometimes called superelevation deficiency) is the numerical difference between the AASHTO Superelevation Criterion and the actual superelevation on a given curve. For

Superelevation Criterion and the actual superelevation on a given curve. For example, for a given set of conditions, assume that a superelevation of .075 would be appropriate on a given curve based on the AASHTO criteria. If the current superelevation on the curve is .055, the superelevation deviation would be .075 - .055 = .02.

Spiral (or Spiral Transition Curve) - A curve with a gradually decreasing radius which is sometimes used to connect a tangent to a curve. A spiral curve provides a driver with a smoother transition into a curve, since it more closely corresponds to a driver's normal turning of the steering wheel. Spiral transition curves have the added advantage of providing a means for changing from a crowned to a superelevated cross-section.

Average Daily Traffic (ADT) - The average total number of vehicles per day which travel over a highway segment (both directions).

Terrain - A description of the vertical and/or horizontal curvature along the overall highway section where the curve of concern is located, as defined by the following:[5]

- Flat - Terrain where highway sight distances are generally long and there are few vertical curves or slopes present.
- Rolling - Terrain with natural slopes which consistently rise above and fall below the highway grade line. Occasionally these slopes restrict normal sight distance.
- Mountainous - Terrain with abrupt longitudinal and transverse changes in the elevation of the ground with respect to the highways.

Sideslope - A measure of the steepness of the roadside slope beyond the shoulder. It is the ratio of amount of drop in elevation for a given lateral distance. A sideslope of 3:1, for example, drops by 1 ft for every 3 ft of horizontal distance. A sketch of the sideslope and other cross-sectional elements is given in figure 2 on the following page.

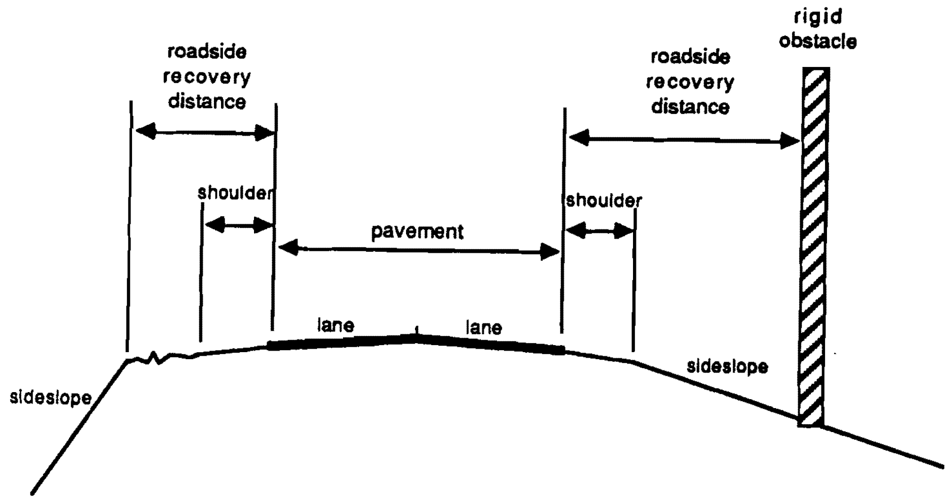



Figure 2. Cross-sectional roadway design features.

Lane Width - The distance (in ft) measured from the roadway centerline to the outside edge of the edgeline, or if no edgeline is visible, to the visible joint separating the lane from the paved shoulder. If no paved shoulder exists, the lane width is measured from the centerline to the edge of the paved surface.

Paved Shoulder Width - The width (in ft) of the concrete or bituminous surface adjacent to the lane.

Unpaved Shoulder Width - The width (in ft) of the prepared surface of grass, soil, gravel, stone, or stabilized gravel surface adjacent to the travel lane.

Roadside Recovery Distance - A relatively flat, unobstructed, and smooth area adjacent to the edge of travel lane (i.e., edgeline) which there is reasonable opportunity for safe recovery of an out-of-control vehicle. The width of the roadside recovery distance on a curve is the lateral distance from the outside edge of the travel lane to the nearest of the following:[5]

- A hinge point where the slope first becomes steeper than 4:1.
- A longitudinal element such as a guardrail or bridge rail.
- An unyielding and hazardous object.

- The ditch line of a non-traversable side ditch.

- Other features, such as a rough or irregular surface, loose rocks, or a watercourse that pose a threat to errant vehicles.

This is similar to the concept of a clear zone, except that the roadside recovery distance includes a recoverable slope; whereas according to the definition in the new AASHTO "Roadside Design Guide,"[6], the clear zone definition also includes a non-recoverable slope.

Along curve sections, the roadway recovery distance may vary considerably or may remain relatively consistent. For calculation purposes, the curve is first divided into 100-ft lengths. Then, measurements are made on each 100 ft segment by observing the obstacles (or steep slope) closest to the roadway, and then measuring the distance from these obstacles to the edge of the travel lane (i.e. edgeline). For a given curve section, it is recommended that one measurement of roadside recovery distance be taken for each 100-ft length along both sides of the curve and averaged together to give a representative value of recovery distance. If recovery distance appears to be relatively similar along the curve, less frequent measures will be acceptable. For very short curves (e.g., less than 100 ft), one or two measurements are sufficient. The user should record the average roadside recovery distance for each curve. The data base used to develop accident relationships is only valid for roadside recovery distances between 0 and 30 ft.

## Procedure Assumptions

The procedures used in this Informational Guide are based on data and information compiled and analyzed only for horizontal curves under the following conditions:[2,3]

- Horizontal curves on rural, two-lane roads with an average daily traffic of between 50 and 10,000.

- Curve lengths between 100 ft and 0.5 mi (2,640 ft).

- A wide variety of curvature, ranging from flat curves of .1 degree up to curves of 60 degrees (per 100 ft of arc). These correspond to curve radii of approximately 57,000 to 100 ft.

- Central angles of .5 degrees up to 120 degrees.
- Both isolated curves and curves in a series. In this guide, a curve is considered to be isolated if it has a tangent of at least 650 ft (.124 mi) on each approach. A separate set of accident reduction factors is provided for the effects on accidents of curve flattening for isolated curves and non-isolated curves.
- Lane widths of 8 to 12 ft.
- Shoulders 0 to 12 ft which are paved or unpaved.

## Relationships of Curve Features

For a given horizontal curve, the central angle (I), degree of curve (D), and curve length (L), are related, as follows:

$$I = (D)(L)(52.8),$$

or equivalently

$$L = (I) \div [(D)(52.8)]$$

where

I = central angle of the curve (in degrees)

D = degree of curve (per 100 ft of arc, as measured in degrees)

L = length of the curve in mi (or fraction of a mi).

When L is expressed in ft, $L = (I/D) \times 100$

Thus, for example, a 2 degree curve with a central angle of 10 degrees would correspond to a curve length of $I/D \times 100 = 10/2 \times 100 = 500$ ft.

Except for major realignment or reconstruction projects on a roadway section, the central angle of the curve is generally assumed to be fixed, and the flattening of the curve is assumed to involve reducing the degree of curve and increasing the overall curve length for a fixed central angle. For example, assume a 30 degree central angle with a 10 degree curve. This would correspond to a curve length of $L = I/D \times 100 = 30/10 \times 100 = 300$ ft, which is a relatively short, sharp curve. Assume that a high accident experience on that curve is observed, and a project is proposed which would flatten the curve to 5 degrees. With the 30 degree central angle, the resulting length of the 5 degree curve would be L = I/D = 30/5 x 100 = 600 ft. Thus, the resulting curve would be twice as long as the original curve but would provide a less severe maneuver for motorists.

As illustrated in figure 3, the original curve would go from $PC_o$ to $PT_o$, while the new curve would extend from $PC_n$ to $PT_n$. Although the new curve is longer than the original curve, the overall new alignment of the highway would be shorter than the original alignment. Thus, when determining the effects of curve flattening on accidents, the full length of the original and new alignment (from $PC_n$ to $PT_n$) must be considered. In other words, a curve flattening project will result in replacing the accidents on the original curve plus the accidents on two tangent segments with the accidents on the new curve alone. This consideration has been accounted for in all accident reduction factors for curve flattening projects in the following chapters.

It should also be mentioned that the sharpness of a curve can affect drivers differently, depending on the design speed of the highway. For example, a 10-degree curve may be considered to be sharp for a design speed of 40 mi/h. However, that same 10-degree curve might be considered relatively flat on a roadway with a design speed of 20 mi/h.

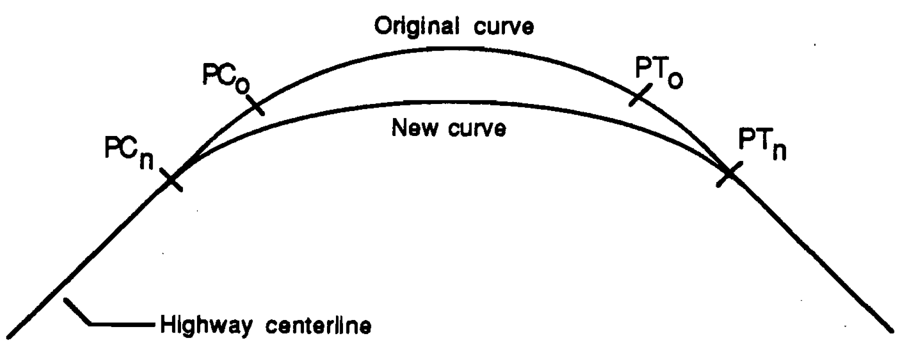
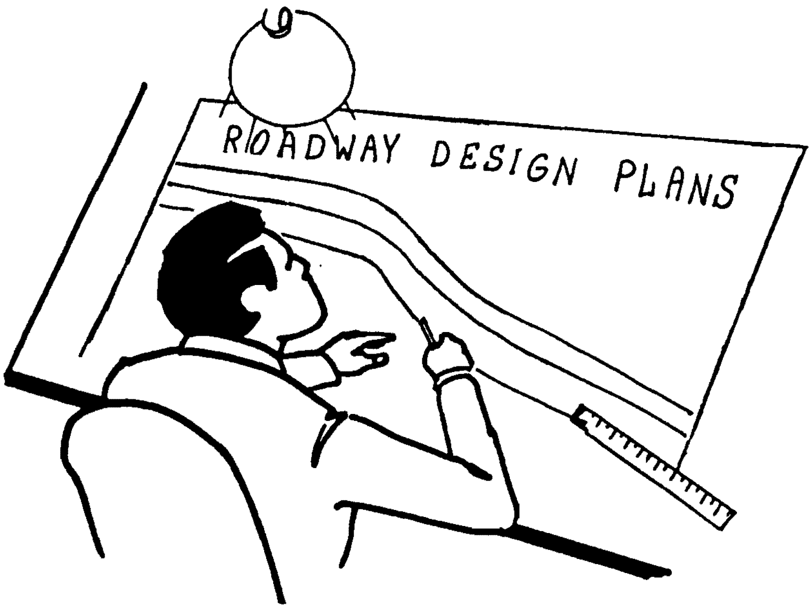



Figure 3. Illustration of original and new alignment due to curve flattening.

# CHAPTER 3 - GENERAL GUIDELINES FOR CURVE DESIGN AND UPGRADING




Designers and highway safety engineers are faced with two distinctly different types of problems regarding horizontal curves: design of new highway sections and treatment or reconstruction of existing highway alignment. The guidelines in this chapter involve curve geometrics, safety, and operations relative to both of these situations.

## Design Guidelines for New Highway Sections

Most highway design in the United States is governed by the procedures, criteria, and design values shown in the AASHTO Policies, such as contained in the AASHTO "Greenbook."(4) Research from two recent FHWA studies on horizontal curves suggests that application of the following design guidelines would significantly improve the overall quality of horizontal curve design:(2,3)

1. **Designers should provide for consistent roadway sections.**

   Over a given highway section, horizontal curves should be designed to minimize the element of surprise to a motorist. This suggests designing curves within a reasonable range of central angle and degree of curve, and the consistent use of adequate superelevation, roadway width and other design features.

Designers should avoid sharp isolated curves and the use of one or more sharp curves after a series of mild curves.

2. **Designers should avoid large central angles wherever possible.**

   Large central angles force designers to choose between long curves or sharp curves, both of which present safety problems. In laying out and selecting new roadway alignments, designers should strive to avoid situations where large central angles are necessary. Central angles greater than 30 degrees may result in safety problems -- greater than 45 degree central angles should be avoided whenever possible.

3. **Designers should minimize the use of controlling curvature (i.e., maximum allowable curvature for a given design speed).**

   Many designers tend to view all curves as equally "safe" within a given design speed. This is not the case. Flatter curves will operate better and tend to have better accident histories, and thus are preferred. Where controlling curvature is used, designers should pay extra attention to the roadside design (in particular, on the outside of the curve).

4. **Designers should use spiral transition curves as a routine part of design, particularly for controlling curves and curves on highways with high design speeds (e.g., 60 mi/h or greater).**

5. **Designers should routinely provide high quality roadside designs, particularly on sharper curves.**

   Wider shoulders, flatter slopes, and greater roadside clear zones in these areas are essential design features.

6. **Designers should use an adequate amount of superelevation on all curves.**

7. **Designers should avoid locating other potentially hazardous features at or near horizontal curves, in recognition of driver difficulty in tracking curvature.**

   Such features to avoid whenever possible include intersections, narrow bridges, major cross-section transitions, and driveways. Other potentially hazardous features include severe reverse curvature with curves in opposing directions separated only by a short tangent alignment.

8. **Designers should provide adequate pavement and shoulder condition, particularly on sharper curves where lateral acceleration and friction demand are the greatest.**

   Increasing pavement skid resistance is often an essential curve improvement, particualrly on curves having a problem with skidding accidents during wet pavement conditions. On highways designed with unpaved shoulders, consideration should be given to paving the shoulders at the sharper curves. Vertical curvature should be provided such that more than minimum stopping sight distance is available throughout the curve.

## Treatment of Existing Curves

Addressing safety problems on existing horizontal curves is distinctly different from the design of horizontal curves on new highway sections. Each location is unique in terms of its constraints, physical conditions, and operational characteristics. There should be an opportunity for the engineer to assess existing conditions. Accident records should reveal whether the curve is a high-accident location, what types of accidents occur, and what are their severities. Speed, encroachment, and other operational studies can also provide guidance on curve accident countermeasures.

The importance of evaluating existing accident patterns and geometry cannot be overemphasized. Every sharp curve with a narrow roadway and/or poor roadsides is not necessarily a safety problem in need of safety improvements. Similarly, the presence of a high accident "hot spot" may not always suggest the need to apply a countermeasure. All research, even the most carefully conducted, has shown that there is much randomness in accident occurrences. It has been stated that less than 10 percent of curves on rural highways are candidates for treatment, with many of these carrying volumes too low to achieve cost-effectiveness.[3]

Generally, countermeasures fall into three major categories: (1) complete reconstruction, (2) physical rehabilitation and/or partial reconstruction, and (3) low-cost spot improvements, such as signing, marking, and delineation. These groups of countermeasures are discussed below.

Curve Reconstruction

Curve reconstruction represents the most costly, but also potentially the most effective means of reducing severe curve accidents. Curve reconstruction may involve flattening of the curve; widening of lanes, shoulders, or both; new pavement; improved roadside; and the addition of a spiral where none previously existed.

Previous research has found that curve flattening, although more expensive than other types of curve improvements, provides the greatest potential for reducing accidents on curves.[2,7] What should be understood is that safety benefits may accrue not only because of the revised curve geometry, but also because a different cross section can be built, new higher friction pavement provided, and other features added. In assessing the cost effectiveness for curve reconstruction, application of the procedures in chapter 4 will enable a reasonable estimate of safety effectiveness.

In any event, the feasibility or cost effectiveness of total curve flattening and reconstruction depends largely on site-specific conditions. The availability and cost of right-of-way, vertical alignment requirements, environmental impacts, and local access changes would all influence any decision to reconstruct a curve.

Besides curve flattening, other reconstruction measures applied to the existing curved alignment may be feasible in given locations. These may include widening the roadway and shoulder on the curve, reconstruction by adding spirals (involving minor relocation), or major roadside improvements, such as flattening roadside slopes and removing trees or other objects along the curve itself. Combinations of the above may also require acquisition of right-of-way, resolution of conflicts with local access, and accommodation of environmental concerns.

Rehabilitation and/or Partial Reconstruction

Less costly measures than curve flattening or roadway widening may be highly effective in treating existing curves. Foremost among these is removal of roadside hazards within the curve itself. Tree removal, utility pole relocation, sideslope flattening, and other such improvements may be cost effective at relatively low traffic volume levels.

Resurfacing of the curve itself to improve skid resistance is also a low-cost solution. This resurfacing can also be used to improve the superelevation in the curve, adjust the superelevation transition, pave the shoulder through the curve, clear roadside obstacles, and eliminate pavement edge dropoff conditions. All of the above can be implemented within existing right-of-way, and with relative ease. The effectiveness of a "package" of curve rehabilitation countermeasures would, of course, depend on the particular site. TRB Special Report 214 provides useful information relative to 3R improvement.(7)

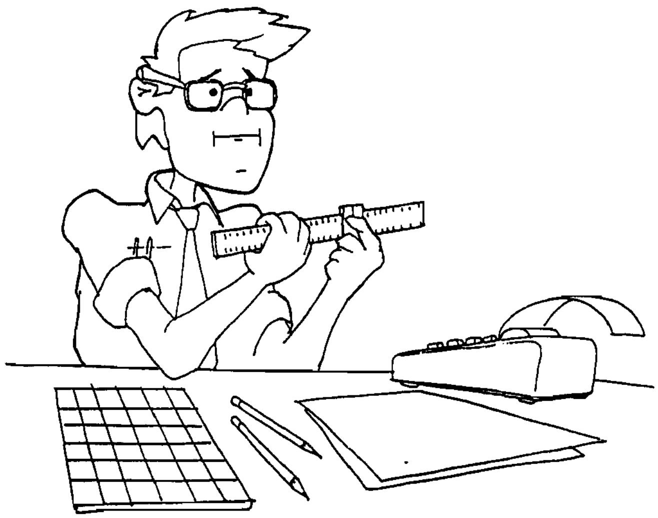
Signing, Marking, and Delineation

Advance warning signs, centerline and edgeline markings, and special delineation schemes have been tested at high accident locations. These types of countermeasures are intuitively appealing because of the low cost and ease of implementation.

Special attention to signing and markings is important along any highway, and particularly at critical locations such as sharp curves. It is clear, however, that the addition of signing, marking and delineation cannot be expected to solve a safety problem on a poorly designed curve. At the same time, proper signing, marking, and delineation in accordance with the "Manual on Uniform Traffic Control Devices" (MUTCD), is an essential ingredient to treating hazardous curves in conjunction with other improvements (e.g., clearing roadsides, widening the roadway, paving the shoulder, flattening the curve, and/or improving the superelevation).(8) Even if construction or reconstruction of a poorly designed curve is not feasible, substandard signing, marking, and delineation should still be improved on hazardous curves.

The preceeding text has provided an overview of the nature of the safety problems on curves and the treatments available to the engineer. The remaining chapters will provide a detailed methodology for deciding what curve improvements are cost effective at a specific location.

# CHAPTER 4 - DETERMINING BENEFITS FROM CURVE IMPROVEMENTS



This chapter may be used to estimate the accident benefits which are expected due to one or more proposed curve improvements on a specific section of two-lane rural road. Chapter 5 will provide the details and forms used in the computation of the cost of the improvements, and chapter 6 will provide information on how to combine these benefits and costs in an incremental benefit-cost analysis for two or more improvement alternatives at a site. Finally, a case study example is shown in chapter 7 illustrating the use of all completed forms.

The procedure detailed in this chapter may be used for computing estimated accident benefits for two-lane rural roads for which one or more of the following improvements are being considered:

- Curve flattening.
- Adding a spiral transition (in conjunction with curve flattening or curve widening).
- Improving deficient superelevation.
- Lane widening.
- Shoulder widening on the curve.
- Shoulder surfacing on the curve.

- Sideslope flattening.
- Removing roadside obstacles to increase the clear recovery distance.

An improvement alternative may involve changing only one curve feature (e.g., curve flattening) or changing several roadway features in the same project (e.g., curve widening, improving superelevation, plus flattening sideslopes). For 3R-type improvements, it is assumed that pavement resurfacing will be the basic improvement with one or more of the improvements listed above also added.

In the narrative below, a series of eight steps are provided for estimating accident benefits. These steps involve the use of several forms and tables and a few simple calculations. The steps include:

Step 1 - Complete the Curve Description on Form A (to summarize the existing conditions at the curve site)

Step 2 - Complete the Improvement Description on Form B

Step 3 - Compute the ADT Over the Future Project Life ($ADT_F$)

Step 4 - Determine the Expected Number of Future Curve Accidents Per Year Without Improvement ($A_{UF}$)

Step 5 - Determine the Accident Reduction (AR) Factor

Step 6 - Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)

Step 7 - Determine the Average Cost per Curve Accident ($C_A$)

Step 8 - Compute Expected Annual Accident Benefits ($B_A$)

The details of each step are described in the following paragraphs. Note that form A is the worksheet used for recording the necessary information concerning the curve characteristics. Form B is the worksheet for completing steps 2 through 8. A separate form B is filled out for each improvement alternative. To assist the reader, the appropriate subsection of form B is shown in bold print following the listing of each step. Appendix A includes complete copies of forms A, B, C, and D.

HORIZONTAL CURVE DESIGN

FORM A - CURVE SITE DESCRIPTION

1. Road Name or Route Identification: NC Route 9999

2. Curve Milepoint Beginning: 1.000 Ending: 1.057 Length: .057 (Mi)

   300 (Ft)

3. Area Type (Check): ✓ Rural

   ____ Urban (If urban, procedures in this manual do not apply.)

> To convert curve radius (R) to Degrees (D):
>
> $$D = \frac{5729.6}{R}$$

4. Degree of curve: 10 (Degrees/100 ft of Arc)

5. Central Angle: 30 (Degrees)

6. Spiral Transitions on Curve Approaches

   ____ Yes ✓ No

7. Actual Superelevation on Curve ($e_A$): .08

8. State Superelevation Policy (check one): ____ .06 ✓ .08 ____ .10

9. Roadway Design Speed: 40 mi/h

10. AASHTO Greenbook Recommended Superelevation for this Curve: .078 ($e_R$)

11. Superelevation Deviation ($e_R - e_A$): ≈ 0

12. Length of Tangent on Curve Approach: Direction 1: 1,200 Ft

    Direction 2: 1,650 Ft

13. Terrain Condition (Check One):

    ____ Flat ✓ Rolling ____ Mountainous

14. Present Average Daily Traffic ($ADT_B$): 1,750

15. Expected Annual Traffic Growth Rate = g = 2 percent per year

16. Lane Width: 10 Ft

17. Paved Shoulder Width: 0 Ft

18. Unpaved Shoulder (e.g., Dirt, Gravel, Turf, Stabilized)

    Width = 0 Ft

Figure 4. Worksheet for summarizing existing conditions at the curve site (form A).

FORM A - CURVE SITE DESCRIPTION (Continued)

19. Typical Sideslope (Check One):

✓ 2:1 or steeper, __3:1, __4:1, __5:1, __6:1, __7:1 or flatter

20. Average Roadside Recovery Distance = 5 Ft

21. Reliable Accident Data for the Section (Check One):

✓ Available ________ Unavailable

Note: If reliable accident data are unavailable, or if no accidents have been reported at the curve in recent years, economic analysis procedures are not approximate. Review step 5A in text and chapter 2 for improvement guidelines to existing curves.

22. Total Curve Accidents = 4 for 5 years

23. Total Curve Accidents per Year Before Improvement = $A_{TB}$

$$= \frac{\text{Total Number of Curve Accidents}}{\text{Number of Years of Data}}$$

$$= 4 \div 5 = 0.8$$

24. (Optional Information): Number of Curve Accidents by Type for 5 Years

| | | | |
|---|---|---|---|
| Single Vehicle (Run-Off-Road and Rollover) | = 3, | or 0.6 | Per Year |
| Head-On and Opposite Direction Sideswipe | = 1, | or 0.2 | Per Year |
| Nighttime Accidents | = 2, | or 0.4 | Per Year |
| Wet-Weather Accidents | = 0, | or 0 | Per Year |

Figure 4. Worksheet for summarizing existing conditions at the curve site (form A) (continued).

## Step 1 - Complete the Curve Description on Form A

The characteristics of each curve site should be recorded on form A (see figure 4). Note that the definitions of the key curve variables are discussed in the previous chapter, along with procedures for obtaining such information. The total accident count for the curve is critical for computing accident savings. Accident reporting errors can sometimes result in inaccurate accident summaries for a given curve site. Thus, it is recommended that hard-copy accident reports be obtained which were reported to have occurred on the curve and on tangent approaches within approximately .05 mi on either end of the curve (if tangents are long enough). A review of the hard-copy accident reports for the time period of concern can assist in determining a more accurate count of the accidents related to the curve.

A summary of accidents by type (run-off-road, etc.) may be useful for selecting countermeasures but is not essential for performing the economic analysis. However, if the total accident count is unknown for the site or if no accidents have been reported at the curve in recent years, an economic analysis is not feasible. Thus, the user should refer to step 4A (which discusses procedures for curves where data is not available) and also to chapter 2 (on guidelines for curve improvements).

**Steps 2 through 8 are included on form B, which is given in full in Appendix A. Under each of the eight following steps, a portion of form B is given in blocks with example calculations.**

## Step 2 - Complete the Improvement Description on Form B

**Step 2: Complete the Following Information on the Proposed Improvement:**

**Description of Alternative** Flatten curve to 5 degrees, Widen lanes to 11 ft, Add 300-ft spirals, Add 8-ft unpaved shoulders, Flatten sideslopes to 4:1, and Remove 50 trees.

| Roadway Feature | Before Treatment | After Treatment |
|---|---|---|
| Degree of Curve | 10 | 5 |
| Spiral Transitions (yes or no) | No | Yes |
| Superelevation | .08 | .08 |
| Superelevation Deviation | ≈ 0 | ≈ 0 |
| Lane Width | 10 | 11 |
| Paved Shoulder Width | 0 | 0 |
| Unpaved Shoulder Width | 0 | 8 |
| Avg. Roadside Recovery Distance | 5 | 20 |
| Typical Sideslope | 2:1 | 4:1 |

One or more project alternatives may be considered for each horizontal curve, and a separate form B should be used for each alternative for each roadway section. Again, an alternative may include only one improvement or a combination of several improvements to be completed together at a given curve site. For example, consider a curve on a rural collector road with the characteristics as given on the form above. Alternative A would include all of the following curve improvements:

- Flatten the curve from 10 degrees to 5 degrees and add a spiral of 300 feet to each end of the curve.
- Widen the 10-ft lanes to 11 ft, and add 8-ft gravel shoulders.
- Flatten the sideslope on the inside and outside of the curve from 2:1 to 4:1 (4-ft height of fill) and remove 50 trees currently located as close as 5 ft from the road to create a 20 ft roadside recovery distance.

For this alternative, a separate form B would be completed. Note that a group of several improvements can be considered as one alternative, as long as they are to be completed together at that site. Step 2 provides details on one proposed alternative (alternative A in this example) along with a listing of conditions before and after treatment. This information is then readily available for use in determining appropriate accident reduction factors, as described later.

Step 3 - Compute the ADT Over the Future Project Life ($ADT_F$)

| |
|---|
| **Step 3: Compute the ADT Over the Future Project Life ($ADT_F$)** |
| **ADT before improvement =** 1,750 **= $ADT_B$** |
| **Project service life =** 20 **years** |
| **Annual growth rate = g =** 2 **percent per year** |
| **Adjustment factor =** 1.24 **= $F_A$ (from table 1)** |
| **Future ADT = $ADT_F$ = ($ADT_B$) x ($F_A$) =** 1,750 **x** 1.24 **=** 2,170 |

The purpose of this step is to estimate the average daily traffic volume over the future project service life of the curve. This is needed since traffic volumes at most sites will not stay constant over a 20-or 30-year period, and changes in traffic volume will likely have an effect on accidents. For any project involving curve flattening, roadway widening, shoulder surfacing, and/ or roadside improvement, the selected service life should correspond to such improvements (e.g., 20 years) even though the resurfacing may only last 4 to 8 years.

To determine the average daily traffic volume over the future project life ($ADT_F$) based on the before ADT ($ADT_B$), the user must first estimate the yearly growth rate (g). Then, using table 1 the adjustment factor, $F_A$, is determined. For example, assume that a lane and shoulder widening alternative is under consideration. The <u>before</u> ADT ($ADT_B$) on that roadway is 1,750 and is expected to increase at the rate of 2 percent per year for a 20-year project life. Using table 1, an adjustment factor ($F_A$) of 1.24 is indicated. Thus, the average ADT to be assumed over the 20-year <u>future</u> project life ($ADT_F$) would be (1,750 x (1.24) = 2,170.

Step 4 - Determine the Expected Number of Future Curve Accidents per Year Without Improvement ($A_{UF}$)

- **Step 4A: If reliable accident data are unavailable for the curve site or if no accidents have been reported at the curve in recent years, an economic analysis of project alternatives is not feasible. Do not continue past step 4, but refer to chapter 2 for guidelines on making safety improvements.**

- **Step 4B: Reliable accident data are available for the curve site.**

  **$A_{TB}$ = 0.8 Total accidents on the curve per year before treatment (from Form A)**

  **Service life = 20**

  **Traffic growth rate = g = 2%/yr.**

  **$F_A$ = The factor (from table 1) to adjust current ADT to future ADT = 1.24**

  **$A_{UF}$ = Future accidents per year in the untreated condition = $A_{TB}$ x $F_A$ = 0.8 x 1.24 = 1.0**

The number of total accidents on the curve without the improvement(s) needs to be known to compute expected accident benefits. If accidents on the curve are unknown, step 4A should be used. If accidents are known, use step 4B.

Step 4A. If the agency does not have reliable accident data or if no known accidents have occurred on the curve in recent years, then a benefit-cost analysis is not feasible, even though the agency may wish to "estimate" the accident experience based on known accidents on similar curves. Instead, the curve of concern should be closely reviewed to determine whether certain improvements are needed to:

1. **Correct obvious deficiencies at the site.** These improvements are needed to minimize the potential for accidents. For example, excessive shoulder edge dropoff suggests the need for immediate corrective action. This is because shoulder edge dropoffs of 4.5 in or more have been found to result in the inability of even professional drivers to steer their vehicle back onto the travel lane without crossing the centerline. Thus, the presence of such shoulder dropoffs can

Table 1. Adjustment factors ($F_A$) for determining future average daily traffic volumes ($ADT_F$).

| Annual Traffic Growth Rate (g) | Project Service Life in Years | | | |
|---|---|---|---|---|
| | 10 | 15 | 20 | 25 |
| - 3% | 0.88 | 0.79 | 0.74 | 0.69 |
| - 2% | 0.91 | 0.85 | 0.81 | 0.78 |
| - 1% | 0.95 | 0.92 | 0.90 | 0.89 |
| 0% (no change) | 1.00 | 1.00 | 1.00 | 1.00 |
| + 1% | 1.06 | 1.08 | 1.11 | 1.14 |
| + 2% | 1.12 | 1.18 | 1.24 | 1.31 |
| + 3% | 1.18 | 1.28 | 1.38 | 1.50 |
| + 4% | 1.25 | 1.39 | 1.55 | 1.73 |
| + 5% | 1.32 | 1.51 | 1.74 | 2.00 |
| + 6% | 1.40 | 1.65 | 1.95 | 2.33 |
| + 8% | 1.56 | 1.95 | 2.47 | 3.16 |

greatly increase head-on and run-off-road accidents. Agencies should also correct for inadequate signing, marking and delineation. Although the accident benefits of such improvements are difficult to quantify for such improvements, proper use of these traffic control devices is important. Such improvements are justified without a cost-effectiveness analysis.

2. **Meet current standards and guidelines.** For example, superelevation and roadway widths which are clearly inadequate can result in driver loss of control and represent a real safety problem which needs to be corrected.

Note that chapter 2 provides additional guidance on the types of curve improvements which should be routinely made, with or without cost-effectiveness justifications. Thus, in the absence of information on accident reductions, the types of roadway deficiencies discussed above should be corrected whenever possible as a part of 3R improvements, with routine roadway maintenance activities, or through other improvement programs. Regardless of the lack of convincing cost-effectiveness data for such improvements, such improvements may well help to reduce serious accidents and injuries. Such corrections can also reduce the tort liability cases brought against an agency resulting from obvious curve deficiencies.

Step 4B. This step should be used for considering the economic impact of curve improvements when an agency has reasonably reliable accident data and one or more accidents have been reported at the curve site in recent years. Such accident information is particularly important when considering such high-cost improvements as curve flattening and major roadway widening to:

- Determine whether a given improvement is economically justified.
- To choose between two or more alternatives based on the expected benefits and costs of each.

Highway agencies typically do not have enough funds to make all roadway improvements which are desired. It may, therefore, be more appropriate to spend those funds at curve sites with greater potential accident savings. Knowledge of accident experience on a curve is helpful in making optimal investments in roadway improvements.

This step first involves determining the number of total accidents on the curve for the past 5 to 10 years, if possible. This information should be recorded on form A, and if known, the number of accidents should be summarized by type:

- Run-off-road (i.e., fixed object or rollover).
- Head-on and opposite direction sideswipe accidents.
- Nighttime accidents.
- Wet-weather accidents.

Such summaries may provide input into site deficiencies and countermeasure selection. For example, a high incidence of fixed and rollover accidents may suggest the need for sideslope flattening, clearing trees, or other roadside improvements or perhaps flattening the curve. A pattern of head-on accidents may suggest the need for widening the lanes and/or shoulders. Summaries by night and day will also help in determining the need for improved delineation and marking on the curve. A history of wet weather accidents may indicate a possible problem with pavement skid resistance. The total number of accidents per year in the before (untreated) condition (= $A_{TB}$) should be taken from form A.

In the example given above, 4 accidents occurred on the curve in the past 5 years, or (4 accs) ÷ (5 yrs) = 0.8 accidents/year = $A_{TB}$ = total accidents per year before improvement. Converting this number to the future accidents in the untreated condition ($A_{UF}$) requires obtaining a volume adjustment factor, $F_A$, from table 1. This is based on the service life and traffic growth rate. For a 20 year service life and a 2 percent increase in traffic per year as given in the example above, the value of $F_A$ = 1.24. Then, $A_{UF} = A_{TB} \times F_A$ = (0.8 accs/year) x (1.24) = .99, or ≈ 1.0 expected future accidents per year if the curve is left untreated.

## Step 5 - Determine the Accident Reduction (AR) Factor

Step 5A - Determine Accident Reduction Factors for Individual Improvements.

The expected percent reduction in total curve accidents which will result due to an improvement project is expressed by the accident reduction factor, AR. The selection of the appropriate AR factor may be made for a given improvement project, as follows (from form B):

| Curve Improvement | Source of AR Factor |
|---|---|
| 1. Curve flattening | Table 2 |
| 2. Upgrading deficient superelevation | Table 3 |
| 3. Adding a spiral transition | Use AR factor of 5 percent for adding spirals to curve |
| 4. Lane widening | Table 4 |
| 5. Widening paved shoulder | Table 4 |
| 6. Widening unpaved shoulder | Table 4 |
| 7. Sideslope flattening | Table 5 |
| 8. Removal of roadside obstacles (increased roadside clear zone) | Table 6 |
| 9. Combining two or more of the improvements into one project | (see Step 5B) |

**Note: Pavement resurfacing is assumed to be included with improvements 1 through 6 above.**

**o Step 5A: Determine AR factors for individual improvement projects using tables 2 through 6, as listed above**

- **Curve flattening (use table 2): AR = 48**
- **Upgrade superelevation: AR = N.A.**
- **Add spiral: AR = 5**
- **Lane widening only (use table 3): AR = 5**

- **Shoulder widening only (use table 3): AR = 24**
- **Roadside improvements (use tables 5 and/or 6): AR = 23 (from table 6)**

**(Note: If curve flattening plus other roadside improvements are proposed for the same alternative, use table 6 for estimating the combined effects of roadside improvements.)**

The accident reduction factors summarized in tables 2 through 6 and discussed in this step are based on several recent FHWA studies on countermeasure effectiveness for horizontal curves on two-lane rural highway sections.(2,3,5)

For purposes of discussion, assume a curve with the following characteristics:

- Degree of curve (D) = 10 degrees.
- Central angle = 30 degrees.
- No spirals exist.
- Superelevation is adequate, i.e., the actual superelevation, $e_A$ = .08 and the desired superelevation, $e_R$ (from the AASHTO Greenbook) = .078.
- Roadway width = 20 ft (i.e., two 10 ft lanes with no shoulders).
- Rolling terrain.
- ADT = 1,750.
- Approach tangent lengths = 1,200 ft and 1,650 ft.
- Sideslope = 2:1, roadside recovery distance = 5 ft (with large trees on the roadside).
- Curve length (L) = (I) ÷ [(D)(52.8)]<br>= .057 mi = 300 ft.

Also consider improvement alternatives A, as follows:

- Flatten the 10 degree curve to 5 degrees and add a spiral of 300 ft to each end of the curve.

- Widen the 10 ft lanes to 11 ft and add an 8-ft gravel shoulder to each side.

- Flatten the sideslope on the inside and outside of the curve from 2:1 to 4:1 (4 ft height of fill) plus remove 50 large trees currently located as close as 5 ft from the road to create a 20-ft roadside recovery distance.

AR factors are discussed below for various types of curve improvements. Alternative A above is used for illustrating the selecting of the appropriate AR factors.

Curve Flattening: The expected AR factors for curve flattening are given in table 2 for various degrees of curve before and after improvement and central angles of 10 to 50 degrees. AR factors are provided for both isolated curves and non-isolated curves, where isolated curves are considered to have tangents of 650 ft (.124 mi) or greater on both ends.

To illustrate the use of table 2, recall that the curve is a 10 degree curve with a 30 degree central angle, with approach tangents of 1,200 feet in one direction and 1,650 feet in the other direction. Hence, this is an isolated curve. The proposed project would flatten the curve to 5 degrees. Based on these conditions, an AR factor of 48 percent would be found from table 2.

Upgrading Deficient Superelevation: As discussed previously, the actual superelevation $e_A$ on a curve (i.e., maximum superelevation measured at a point near the curve center) should be compared with the recommended superelevation, $e_R$, as determined based on the AASHTO Greenbook and the agency's roadway design criteria. The algebraic difference of $e_R - e_A = e_D$ is considered to be the "superelevation deviation," or the difference between the recommended and actual superelevation. Values of AR factors to be used for upgrading the superelevation deviation, $e_D$, to the desired level are shown in table 3. Having too much superelevation (i.e., $e_A > e_R$) does not necessarily imply a problem, unless an accident or operational problem is observed (e.g., vehicles sliding to the inside of the curve). In the above example, the actual superelevation was slightly higher than the recommended superelevation (i.e., $e_A = .08$, $e_R = .078$) and was considered quite adequate, so no improvement was necessary.

Adding a Spiral Transition: Providing a spiral transition to an existing curve is sometimes accomplished in conjunction with a resurfacing project, particularly where a curve flattening and/or curve widening project is

Table 2. Percent reduction (AR) in total accidents due to horizontal curve flattening -- non-isolated and isolated curves.

| Degree of Curve | | Central Angle in Degrees | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | | 20 | | 30 | | 40 | | 50 | |
| Original (Do) | New (Dn) | Non-Isolated | Isolated* | Non-Isolated | Isolated | Non-Isolated | Isolated | Non-Isolated | Isolated | Non-Isolated | Isolated |
| 30 | 25 | 16 | 17* | 16 | 17 | 16 | 17 | 15 | 16 | 15 | 16 |
| 30 | 20 | 33 | 33 | 32 | 33 | 31 | 33 | 31 | 33 | 30 | 33 |
| 30 | 15 | 49 | 50 | 48 | 50 | 47 | 50 | 46 | 50 | 46 | 50 |
| 30 | 12 | 59 | 60 | 57 | 60 | 56 | 60 | 55 | 60 | 55 | 60 |
| 30 | 10 | 65 | 67 | 64 | 66 | 63 | 66 | 62 | 66 | 61 | 66 |
| 30 | 8 | 72 | 73 | 70 | 73 | 69 | 73 | 68 | 73 | 68 | 73 |
| 30 | 5 | 82 | 83 | 80 | 83 | 79 | 83 | 78 | 83 | 78 | 83 |
| 25 | 20 | 19 | 20 | 19 | 20 | 18 | 20 | 18 | 20 | 17 | 20 |
| 25 | 15 | 39 | 40 | 38 | 40 | 36 | 40 | 36 | 40 | 35 | 40 |
| 25 | 12 | 50 | 52 | 49 | 52 | 48 | 52 | 46 | 52 | 46 | 51 |
| 25 | 10 | 58 | 60 | 56 | 60 | 55 | 60 | 54 | 59 | 53 | 59 |
| 25 | 8 | 66 | 68 | 64 | 68 | 62 | 68 | 61 | 67 | 60 | 67 |
| 25 | 5 | 77 | 80 | 75 | 80 | 74 | 79 | 72 | 79 | 72 | 79 |
| 20 | 15 | 24 | 25 | 23 | 25 | 22 | 25 | 21 | 25 | 20 | 24 |
| 20 | 12 | 38 | 40 | 36 | 40 | 35 | 40 | 34 | 39 | 33 | 39 |
| 20 | 10 | 48 | 50 | 45 | 50 | 44 | 49 | 42 | 49 | 41 | 49 |
| 20 | 8 | 57 | 60 | 54 | 60 | 52 | 59 | 51 | 59 | 50 | 59 |
| 20 | 5 | 71 | 75 | 68 | 74 | 66 | 74 | 64 | 74 | 64 | 74 |
| 15 | 10 | 30 | 33 | 28 | 33 | 26 | 33 | 25 | 32 | 24 | 32 |
| 15 | 8 | 43 | 46 | 40 | 46 | 37 | 46 | 35 | 45 | 34 | 45 |
| 15 | 5 | 61 | 66 | 56 | 66 | 53 | 65 | 51 | 65 | 50 | 65 |
| 15 | 3 | 73 | 79 | 68 | 79 | 64 | 78 | 63 | 78 | 63 | 78 |
| 10 | 5 | 41 | 49 | 36 | 48 | 32 | 48 | 29 | 47 | 28 | 47 |
| 10 | 3 | 58 | 69 | 50 | 68 | 45 | 67 | 43 | 66 | 42 | 66 |
| 5 | 3 | 22 | 37 | 15 | 35 | 13 | 33 | 11 | 32 | 11 | 31 |

*Isolated curves include curves with tangents of 650 ft (.124 mi) or greater on each end.

Table 3. Accident reduction factors corresponding to improving superelevation.

| $e_D$ | AR Factor Due to Upgrading Superelevation |
|---|---|
| .01 to .019 | 5 percent |
| $\geq$.02 | 10 percent |

involved. The presence of spiral transition curves on both ends of a curve has been determined to result in a 5 percent reduction in total curve accidents, everything else being equal. Thus, a 5 percent AR factor should be used when adding spirals. Step 5B discusses the proper way to combine two or more AR factors, such as when adding a spiral to a curve along with other geometric improvements (e.g., curve flattening). In the example above, spirals were to be added as a part of Alternative A, which would correspond to an additional AR factor of 5 percent.

Widening Lanes and Shoulders on a Curve: AR factors are given in table 4 for widening lanes and/or shoulders on horizontal curves. From the left column of the table, the user should select the amount of lane or shoulder widening (in ft) which is proposed. The columns then provide the AR factors for widening of lanes, paved shoulders and unpaved shoulders, respectively.

To illustrate the use of table 4, recall that alternative A above also involved widening a 20-ft roadway (two 10-ft lanes with no shoulder) to 22 ft of paved surface with 8-ft gravel shoulders. Table 4 indicates a 5 percent accident reduction be applied due to widening the lanes a total of 2 ft (from 20 to 22 ft). Then, adding 8-ft gravel shoulders (i.e., 16 total ft of shoulder widening) would further reduce the resulting number of accidents by 24 percent. Note: Combining the 5 percent and 24 percent AR factors does not involve merely adding the two numbers together. Step 5B describes a method for combining two or more AR factors. It is also important to emphasize that some lane and shoulder widening projects are made within the same right-of-way, which results in steepened sideslopes. However, sideslopes should never be

Table 4. Percent reduction in accidents due to lane widening, paved shoulder widening, and unpaved shoulder widening.

| Total Amount of Lane or Shoulder Widening (ft) | | Percent Accident Reduction | | |
|---|---|---|---|---|
| Total | Per Side | Lane Widening[1] | Paved Shoulder Widening | Unpaved Shoulder Widening |
| 2 | 1 | 5 | 4 | 3 |
| 4 | 2 | 12 | 8 | 7 |
| 6 | 3 | 17 | 12 | 10 |
| 8 | 4 | 21 | 15 | 13 |
| 10 | 5 | -- | 19 | 16 |
| 12 | 6 | -- | 21 | 18 |
| 14 | 7 | -- | 25 | 21 |
| 16 | 8 | -- | 28 | 24 |
| 18 | 9 | -- | 31 | 26 |
| 20 | 10 | -- | 33 | 29 |

[1]Values of lane widening correspond to a maximum widening of 8-ft to 12-ft lanes for a total of 4 ft per lane or a total of 8 ft of widening.

steepened (particularly steeper than 4:1) in conjunction with a roadway widening project, since this could lead to more rollover accidents and increased accident severity.

Sideslope flattening: The percent reduction in total curve accidents due to sideslope flattening on the curve is given in table 5, as taken from reference 2. Locate the sideslope in the before condition in the left column and the proposed sideslope in the after condition across the top of the table. The number in the table corresponding to those two values yields the AR factor. For example, flattening a 2:1 sideslope to 4:1 would result in an expected 6 percent reduction in total accidents on the curve (assuming no other roadside improvements are made).

Table 5. Summary of expected percentage reduction in total curve accidents due to sideslope flattening.(2)

| Sideslope in Before Condition | Sideslope in After Condition | | | |
|---|---|---|---|---|
| | 4:1 | 5:1 | 6:1 | 7:1 or Flatter |
| 2:1 | 6 | 9 | 12 | 15 |
| 3:1 | 5 | 8 | 11 | 15 |
| 4:1 | - | 3 | 7 | 11 |
| 5:1 | - | - | 3 | 8 |
| 6:1 | - | - | - | 5 |

Removal of Roadside Obstacles: AR factors are given in table 6 corresponding to increasing the roadside clear recovery distance by removing trees, relocating utility poles, providing traversable drainage structures, or other roadside improvements which increases the roadside clear zone. Thus, an increase in recovery distance 5 ft would be expected to reduce total curve accidents by 9 percent. Providing 20 ft of additional roadside recovery distance (e.g., from 5 to 25 ft) should reduce curve accidents by 29 percent. Part of alternative A (described earlier) involved removing trees between 5 ft and 20 ft from the travel lanes, a 15 ft increase in the roadside recovery distance. This should reduce total curve accidents by 23 percent.

Note that flattening the sideslope from 2:1 to 4:1 would be needed to provide the full 20 ft roadside recovery distance, since merely cutting down trees on a 2:1 slope would not prevent vehicles from rolling over on the sideslope. Note that table 5 should be used where sideslope flattening is conducted without other roadside improvements. Table 6 should be used for roadside improvements which include removal or relocation of roadside obstacles (e.g., clearing trees, relocating utility poles), with or without sideslope flattening in cases where the recovery area distance is increased as a result of the improvement. Thus, the <u>combined</u> roadside improvements in alternative A (i.e., clearing trees plus flattening the sideslope to 4:1) will result in an expected reduction of 23 percent.

Table 6. Reduction in total curve accidents due to increasing roadside clear recovery distance.[1]

| Amount of Increased Roadside Recovery Distance (feet) | Percent Reduction in Total Curve Accidents |
|---|---|
| 5 | 9 |
| 8 | 14 |
| 10 | 17 |
| 12 | 19 |
| 15 | 23 |
| 20 | 29 |

[1]Values in this table were derived from reference 6, by adjusting to the percent of <u>total</u> accidents.

The AR factors for alternative A are recorded on form B, as illustrated previously. For roadway improvements where only one AR factor applies, go directly to step 6. However, for improvements involving the selection of two or more AR factors (e.g., curve flattening plus roadside improvements), then these AR factors <u>cannot</u> be simply added together. Instead, use step 5B to correctly determine the overall AR factor.

Step 5B - Combine Individual AR Factors

- **Step 5B: Combine Individual AR Factors**

  **Overall accident reduction (AR) from more than one improvement:**

  $$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)(1 - AR_5) \ldots\ldots$$

  $$= 1 - (1 - .48)(1 - .05)(1 - .05)(1 - .24)(1 - .23) = .725 \text{ or } .72$$

**where:**

$AR_1$, $AR_2$ and $AR_3$, etc. are accident reduction factors for improvements 1, 2, 3, etc., respectively

Step 5B is only necessary to determine the combined effect of two or more AR factors. Consider alternative A given previous, which includes a combination of the following improvements:

| | AR Factor |
|---|---|
| Curve flattening | 48 |
| Adding spirals | 5 |
| Widening lanes by 1 ft | 5 |
| Adding 8-ft unpaved shoulders | 24 |
| Flattening sideslope plus clearing trees | 23 |

The combined effect of these AR factors must not be simply added. Instead, the overall accident reduction (AR) should be computed as follows:

$$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4) \ldots.$$

Where:

$AR_1$ = the accident reduction factor from the first improvement (i.e., in this case 48 percent)

$AR_2$ = the accident reduction factor from the second improvement (i.e., 5 percent)

$AR_3$ = the accident reduction factor from the third improvement, etc.

$$AR = 1 - (1 -.48)\ (1 -.05)\ (1 -.05)\ (1 -.24)\ (1 -.23)$$

$$= 1 - (.52)\ (.95)\ (.95)\ (.76)\ (.77)$$

$$= .725$$, or a 72 percent reduction in total curve accidents.

The process can be repeated with numerous AR factors being combined, but the value of AR will never exceed a 100 percent reduction in accidents. The combined accident reduction factor is then used in computing accident benefits in step 6 below.

Step 6 - Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)

**The net number of total curve accidents reduced per year ($\Delta A$) is computed as follows:**

$$\Delta A = (A_{UF}) \times (AR)$$

**where:**

**$A_{UF}$ = future accidents per year in the untreated condition (from step 4B)**

**AR = the combined accident reduction factor (from step 5B).**

**Thus, $\Delta A = A_{UF} \times AR$ = 1.0 x .72 = .72 accidents reduced per year**

Thus, for an improvement with 1.0 total curve accidents per year expected in the future untreated condition (based on future ADT) and an AR of 72 percent,

$$\Delta A = (1.0)\ (.72) = .72$$ curve accidents reduced per year.

Step 7 - Determine the Average Cost per Curve Accident ($C_A$)

**$C_A$ = $ 59,000 (Use $59,000 if unknown)**

After estimating expected reductions in annual curve accidents, a unit accident cost is needed to allow for computing accident benefits (savings in dollars). Numerous sources are available for such unit accident costs based on different assumptions and cost information. Examples of unit accident cost estimates include: National Safety Council (NSC) costs; (2) National Highway Traffic Safety Administration (NHTSA) costs; costs by Miller et al.; the 1988 FHWA Technical Advisory, and others.[9,10,11,12]

The average cost per curve accident was computed in a recent FHWA curve study based on distributions of curve-related crashes by severity as shown in table 7 below.[2]

Table 7. Costs per crash on curves by severity (in 1988 dollars).[2]

| Crash Severity | Cost | Percent of Crashes |
|---|---|---|
| Fatal | $1,825,000 | 2.55 |
| Serious (A-type) | $ 50,000 | 11.00 |
| Moderate (B-type) | $ 20,000 | 20.50 |
| Minor (C-type) | $ 9,000 | 13.30 |
| Property Damage Only | $ 3,000 | 52.65 |

Average = (\$1,825,000) (.0255) + (\$50,000) (.11)

+ (\$20,000) (.205) + (\$9,000) (.133) + (\$3,000) (.5265)

= approximately \$59,000

The costs per accident were based on a 1988 FHWA Technical Advisory[12] and updated to 1990 costs in a recent FHWA curve study.[2] While these costs are higher than those of the National Safety Council, they are more in line with costs which have become more widely accepted in recent years in other transportation disciplines. The cost of $59,000 per curve accident is recommended.

Step 8 - Compute Expected Annual Accident Benefits ($B_A$)

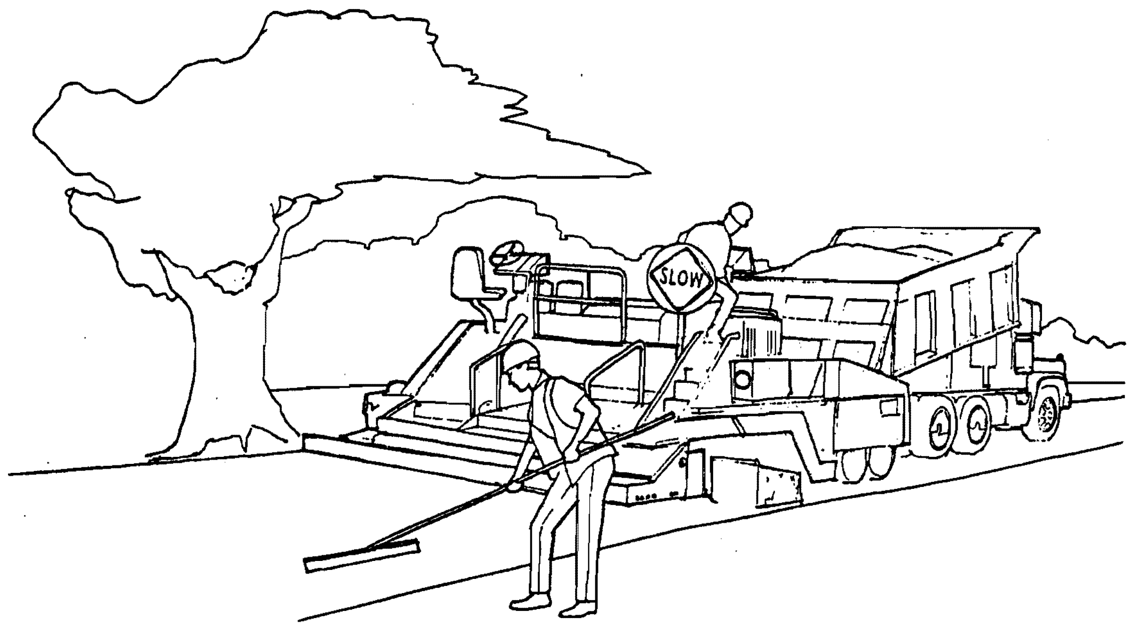
| | | |
|---|---|---|
| | $B_A$ = | **accident benefits per year based on the net reduction in curve accidents** |
| | | = $(\Delta A) \times (C_A)$ = .72 x $ 59,000 = $ 42,480 |
| **where,** | | |
| | $\Delta A$ = | **net reduction in accidents per year (see Step 6)** |
| | $C_A$ = | **average cost of a curve accident (see Step 7)** |

Accident benefits ($B_A$) due to a net reduction in curve accidents are calculated on a yearly basis, based on the net accident reduction ( A) and the average cost of an accident ($C_A$), i.e.,

$$B_A = (\Delta A) \times (C_A)$$

Thus, as in the previous example, a roadway improvement which would reduce .72 curve accidents per year at a cost of $50,000 per accident would yield a benefit of (.72) x ($59,000) = $42,480 per year.

The next chapter provides information for computing costs for curve improvement projects which can be used along with accident benefit information in an economic analysis.



# CHAPTER 5 - DETERMINING THE COSTS OF CURVE IMPROVEMENTS


This chapter focuses on the direct costs to a highway agency for implementing horizontal curve-related improvement projects. Because of the variability in maintenance costs, no attempt was made to estimate these costs for this study. Implementation costs are presented in this chapter for general guidance purposes only. Each agency should draw upon its own data and expertise to obtain their best implementation cost estimates. This is because the example costs given in this chapter are based on information from several recent studies on roadway improvements but may not reflect the construction practices, material sources, wage rates, climate and other factors which vary widely from agency to agency. An agency may also have readily available maintenance cost data which can be included along with implementation costs.

## General Comments Concerning Cost Data Developments

Many of the curve improvements described in this chapter could be made in conjunction with 3R projects where resurfacing is included. The types of curve improvements addressed in this chapter are:

- Curve flattening.
- Lane and shoulder widening and shoulder surfacing.
- Adding a spiral in conjunction with curve flattening.
- Sideslope flattening.
- Roadside improvements.

## Curve Flattening Costs

Estimated costs for flattening curves are given in table 8 for various central angles and degrees of curve before and after widening. For example, to find the cost for flattening a 30 degree curve to 15 degrees with a 40 degree central angle, select the third line from the top of table 8. Proceed over to the 40 degree column and read the cost of $182,100. Notice that costs increase with:

- Increasing amount of flattening (e.g., flattening a 20 degree curve to 8 degrees costs more than flattening it to 15 degrees).
- Increasing central angle (e.g., flattening a 20 degree curve to 10 degrees costs more for a 40 degree central angle than a 20 degree central angle).
- Decreasing original degree of curve for a given central angle and a fixed (say, 5 degrees) amount of flattening. For example, flattening a 30 degree curve by 5 degrees (to 25 degrees) costs less than flattening a 15 degree curve by 5 degrees. This is because flattening a 30 degree curve to 25 degrees will require much less length of new curve than flattening a 15 degree curve to 10 degrees. (See chapter 2 for calculating the lengths of curves for various degrees of curve for a given central angle).

The cost values in table 8 for curve flattening were based on an update of information from TRB Special Report 214.(7) While these values may be reasonable cost estimates for a variety of situations, agencies are urged to consider their own cost estimates when available.

## Cost of Adding Spirals with Curve Flattening

In flattening and/or widening a curve, a spiral could be added on both ends of the curve. The additional cost for adding spirals in most cases will be small when compared to the total cost of the curve flattening project. In fact, the cost for design and construction of the new curve usually can be assumed to be approximately the same regardless of whether spiral transition curves are added. The presence of spiral transition curves has been found to reduce curve accidents. Thus, provided costs are minimal, the addition of spirals is recommended.

Table 8. Cost (in thousand $) of curve flattening without addition of spiral (in 1988 dollars).[2]

| Degree of Curve Before | After | Central Angle 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 25 | 42.8 | 71.0 | 95.1 | 116.7 | 136.7 | 155.4 | 173.1 | 190.0 | 206.2 |
| 30 | 20 | 52.1 | 87.1 | 117.2 | 144.4 | 169.6 | 193.3 | 215.8 | 237.4 | 258.0 |
| 30 | 15 | 64.3 | 108.6 | 147.1 | 182.1 | 214.7 | 245.5 | 274.9 | 303.0 | 330.1 |
| 30 | 12 | 73.7 | 125.6 | 170.9 | 212.4 | 251.3 | 288.0 | 323.1 | 356.9 | 389.5 |
| 30 | 10 | 81.4 | 139.5 | 190.8 | 237.8 | 282.0 | 323.9 | 364.0 | 402.6 | 440.0 |
| 30 | 8 | 90.7 | 156.8 | 215.5 | 269.6 | 320.6 | 369.2 | 415.9 | 460.9 | 504.5 |
| 30 | 5 | 110.3 | 194.1 | 269.6 | 340.1 | 407.0 | 471.2 | 533.1 | 593.2 | 651.7 |
| 25 | 20 | 47.3 | 79.1 | 106.5 | 131.2 | 154.1 | 175.6 | 196.0 | 215.6 | 234.3 |
| 25 | 15 | 59.3 | 100.3 | 135.8 | 168.1 | 198.2 | 226.7 | 253.8 | 279.7 | 304.8 |
| 25 | 12 | 68.8 | 117.2 | 159.5 | 198.2 | 234.5 | 268.8 | 301.5 | 333.0 | 363.4 |
| 25 | 10 | 76.5 | 131.2 | 179.4 | 223.6 | 265.2 | 304.6 | 342.3 | 378.6 | 413.8 |
| 25 | 8 | 86.0 | 148.7 | 204.3 | 255.7 | 304.0 | 350.1 | 394.3 | 437.0 | 478.4 |
| 25 | 5 | 106.0 | 186.6 | 259.2 | 327.0 | 391.4 | 453.1 | 512.6 | 570.4 | 626.6 |
| 20 | 15 | 53.8 | 90.9 | 123.1 | 152.5 | 179.8 | 205.6 | 230.1 | 253.7 | 276.4 |
| 20 | 12 | 63.2 | 107.7 | 146.6 | 182.2 | 215.4 | 247.0 | 277.1 | 306.0 | 333.9 |
| 20 | 10 | 71.0 | 121.7 | 166.4 | 207.4 | 245.9 | 282.5 | 317.5 | 351.2 | 383.8 |
| 20 | 8 | 80.6 | 139.3 | 191.4 | 239.6 | 284.9 | 328.0 | 369.5 | 409.5 | 448.2 |
| 20 | 5 | 101.1 | 177.9 | 247.1 | 311.7 | 373.0 | 431.8 | 488.6 | 543.6 | 597.2 |
| 15 | 12 | 56.7 | 96.5 | 131.4 | 163.3 | 193.2 | 221.4 | 248.4 | 274.4 | 299.4 |
| 15 | 10 | 64.4 | 110.5 | 151.0 | 188.3 | 223.2 | 256.4 | 288.2 | 318.8 | 348.3 |
| 15 | 8 | 74.1 | 128.1 | 176.0 | 220.3 | 261.9 | 301.6 | 339.7 | 376.5 | 412.2 |
| 15 | 5 | 95.0 | 167.2 | 232.3 | 293.0 | 350.6 | 405.9 | 459.3 | 511.0 | 561.4 |
| 10 | 8 | 65.8 | 113.8 | 156.4 | 195.7 | 232.7 | 268.0 | 301.9 | 334.5 | 366.2 |
| 10 | 5 | 87.1 | 153.2 | 212.9 | 268.5 | 321.4 | 372.0 | 420.9 | 468.3 | 514.5 |
| 8 | 5 | 83.0 | 146.1 | 202.9 | 255.9 | 306.3 | 354.6 | 401.2 | 446.4 | 490.4 |
| 8 | 3 | 108.0 | 193.8 | 272.3 | 346.5 | 417.5 | 486.1 | 552.8 | 617.7 | 681.2 |
| 5 | 3 | 100.5 | 180.2 | 253.3 | 322.2 | 388.3 | 452.1 | 514.0 | 574.5 | 633.5 |

## Lane and Shoulder Improvement Costs

The cost of widening lanes and shoulder is summarized in table 9, which varies by type of terrain.(2)

Table 9. Costs (1988 dollars) for widening lanes and shoulders on curves per ft of width (both directions) per mi.(2)

| Terrain | Lanes | Paved Shoulders | Unpaved Shoulders |
|---|---|---|---|
| Flat | $42,150 | $15,700 | $ 5,150 |
| Rolling | $50,000 | $23,750 | $13,250 |
| Mountainous | $76,450 | $50,000 | $39,450 |

Note that costs in table 9 are in terms of per ft of widening (in both directions per mi of curve). Thus, the cost for widening a roadway 2 ft in both directions (from 9- to 11-ft lanes) on a .3 mile curve in flat terrain would be:

(2 ft of lane widening) x ($42,150/ft of widening per mi) =

$84,300 per mi.

Since the curve is .3 mi, the cost would be ($84,300 per mi) x (.3 mi) = $25,290. Providing 3-ft unpaved shoulders on that curve would cost:

(3 ft) x ($5,150/ft of widening per mi) = $15,450 per mi

For a .3 mi curve length, the cost would be ($15,450/mi) x (.3 mi) = $4,635. Costs can then be added for combinations of lane and shoulder improvements.

## Superelevation Costs

The upgrading of deficient superelevation would most likely be done in conjunction with a resurfacing project. A lack of enough superelevation would require more paving material than otherwise expected to elevate the outside of the curve. This additional cost will vary depending on the amount of superelevation deficiency, the length of the curve, the labor costs, and other related costs. However, because of the importance of providing adequate superelevation, such curve improvements should be routinely made as needed in conjunction with 3R improvements. Providing sufficient superelevation to a curve is essential, and should not require a cost-effectiveness analysis to justify such improvements.

## Roadside Improvement Costs

The estimated costs of some common roadside improvements on curves are presented in table 10 and include improvements involving trees, signs, luminaires, mailboxes, fire hydrants, impact attenuators, guardrail, and fences. On a per unit basis, mitigating these hazards can be relatively inexpensive. Costs were determined from approximately 10 highway agencies and summarized in table 10. Because of the wide range of costs, the unit cost values are summarized for each item in terms of a high (upper limit), median, and low cost (i.e., lower limit). The high and low costs for many improvements vary widely.

Other roadside improvements that are often used include retrofitting signs and luminaires with breakaway devices. However, these costs also tend to vary widely among projects, and the user is advised to follow agency procedure in determining these costs. Relocating utility poles is another possible roadside improvement on curves. Because types of poles and power/communication lines vary so widely, the costs for these improvements are shown in table 11 by type of pole and rural/urban location.(13)

## Sideslope Flattening Costs

The estimated costs of flattening several common types of sideslopes are given in table 12. The columns of the table show the original slope and the new slope, and costs are given for various heights of fill. For example, flattening a 2:1 slope to a 4:1 for a 4-ft height of fill on a 0.2 mi curve would cost ($38,100/mi) x (.2 mi) = $7,620 on each side of the road. The cost would be doubled ($15,240) for sideslope flattening on both sides of the road. These cost values were based on information from TRB Special Report 214 which were updated to 1988 dollars.(7)

Table 10. Roadside improvement costs.

| Object | Action | Unit | Unit Costs (1988 $) | | |
|---|---|---|---|---|---|
| | | | High | Median | Low |
| Trees | Remove | Each | $ 620 | $ 220 | $ 78 |
| | Clear & Grub | Acre | 9,000 | 3,900 | 1,100 |
| Small sign | Relocate | Each | 490 | 220 | 78 |
| | Remove | Each | 250 | 45 | 17 |
| Large sign | Relocate | Each | 3,360 | 1,230 | 560 |
| | Remove | Each | 670 | 200 | 28 |
| Luminaire support | Relocate | Each | 1,680 | 670 | 340 |
| Mailboxes | Relocate | Each | 340 | 130 | 67 |
| Fire hydrant | Relocate | Each | 2,470 | 1,230 | 620 |
| | Remove | Each | 380 | 280 | 200 |
| Guardrail | Relocate | L.F.* | 21.3 | 9.0 | 6.7 |
| | Remove | L.F. | 6.2 | 1.7 | .8 |
| | Install New | L.F. | 34.8 | 11.2 | 8.5 |
| Cable guardrail | Relocate | L.F. | 5.6 | 3.9 | 2.8 |
| | Remove | L.F. | 3.4 | 1.2 | .8 |
| | Install New | L.F. | 10.1 | 6.7 | 3.6 |
| Guardrail end-treatment | Install New | Each | 900 | 560 | 390 |
| Chain-link fence | Relocate | L.F. | 22.4 | 14.6 | 11.2 |
| | Remove | L.F. | 6.7 | 3.1 | 1.9 |
| Fence | Relocate | L.F. | 11.2 | 3.4 | 1.1 |
| | Remove | L.F. | 5.6 | .9 | .2 |
| Impact attenuator-hydraulic type | Install New | Each | 29,100 | 22,400 | 11,200 |
| Impact attenuator-sand-filled type | Install New | Each | 6,700 | 4,480 | 3,360 |

*L.F. = linear ft

Table 11. Summary of costs (1988 dollars) for relocating utility poles.(13)[1]

| Type of Utility Pole or Lines | Installation Costs (Dollars per Pole) | | | |
|---|---|---|---|---|
| | Rural | | Urban | |
| | Range | Avg | Range | Avg |
| Wood Telephone Poles | $210-$770 | $ 440 | $210-$970 | $ 550 |
| Wood Power Poles Carrying <69 KV Lines | $190-$5,150 | $ 1,640 | $190-$5,150 | $1,850 |
| Non-Wood Poles (Metal, Concrete or Other) | $810-$4,190 | $ 2,240 | $810-$4,340 | $2,330 |
| Heavy Wood Distribution and Wood Transmission Poles | $750-$7,080 | $ 2,920 | $640-$9,140 | $3,790 |
| Steel Transmission Poles | $12,900-$38,600 | $25,800 | $25,800-51,500 | $38,600 |

[1]Based on information from 31 utility companies in 20 States throughtout the U.S.

Table 12. Summary of costs (in 1988 costs in $ thousands) for flattening sideslopes on fill sections.[(2)1]

| Original Slope | New Slope | Construction Cost per mi ($ thousands) for One Side of Highway | | | |
|---|---|---|---|---|---|
| | | Fill Height = 2 ft | Fill Height = 4 ft | Fill Height = 6 ft | Fill Height = 8 ft |
| 1:1 | 2:1 | 5.6 | 19.1 | 41.5 | 74.0 |
| | 3:1 | 10.1 | 37.0 | 83.0 | 145.7 |
| | 4:1 | 14.6 | 56.0 | 123.3 | 217.5 |
| 2:1 | 3:1 | 5.6 | 20.2 | 42.6 | 75.1 |
| | 4:1 | 10.1 | 38.1 | 83.0 | 146.9 |
| | 6:1 | 20.2 | 75.1 | 164.8 | 290.3 |
| 3:1 | 4:1 | 5.6 | 20.2 | 43.7 | 76.2 |
| | 6:1 | 15.7 | 57.2 | 125.6 | 219.7 |

[1]No right-of-way costs are included.

## Project Service Life

For any projects involving curve flattening, adding spirals, roadway widening, shoulder surfacing, and/or roadway improvements, service lives of 15 to 25 years would be considered appropriate. The pavement overlay may last only 4 to 8 years, and pavement resurfacing may be needed several more times over the 15- to 25-year project life. However, some future maintenance costs would be needed even if no cross-section improvements had been made, so the net change in annual maintenance costs due to the project may be assumed to be negligible. More specific agency costs may be used if known.

## Use of Form C

The costs for each project alternative may be recorded on form C (see figure 5). The curve location and improvements are filled out at the top of the form. Then the seven steps shown in form C are completed. Assume, for example, the following project alternative (i.e., alternative A as given earlier):

- Flattening a 10 degree curve to 5 degrees with a 30 degree central angle and add a spiral of 300 ft to each end.
- Widen the 10-ft lanes to 11-ft and add 8-ft gravel shoulders to each side (rolling terrain).
- Flatten the sideslope on the inside and outside of the curve from 2:1 to 4:1 (4-ft height of fill) and clear 50 trees currently located as close as 5-ft from the road back to create a 20 ft roadside recovery distance.

### Step 1 - Determine Cost for Curve Flattening

From table 8, the cost for flattening a 10 degree curve to 5 degrees with a 30 degree central angle is $212,900.

### Step 2 - Estimate the Additional Cost for Adding Spirals

Since curve flattening is proposed, the additional cost to add spiral transition curves was estimated to be negligible in this case.

## HORIZONTAL CURVE DESIGN

### FORM C - CURVE IMPROVEMENT COSTS

(Complete One of These Forms for Each Project Alternative)

Curve Location ______________________ Alternative No. ____ of ____

Improvement Project(s) Included as Part of this Alternative:

1. ______________________ 2. ______________________
3. ______________________ 4. ______________________
5. ______________________ 6. ______________________

Step 1 - Determine Cost for Curve Flattening.

Degree of curve before flattening = ______ after flattening = ______
Central angle = ______

Estimated cost for flattening (from table 8) = $__________

Step 2 - Estimate the Additional Cost for Adding Spirals.

Length of each spiral (from AASHTO Greenbook) = __________
Estimated cost for adding spiral = $__________

Step 3 - Determine the Added Cost for Upgrading Superelevation.

Cost for superelevation upgrading = $__________

Step 4 - Compute Cost for Lane and Shoulder Widening.

Curve Length (L) = ________ mi

| | Column A | Column B | Column C |
|---|---|---|---|
| Type of Widening | Amount of Widening in ft (Each Side) | Cost per foot (From table 9) | Column A x Column B |
| Lane | ____ | ______ | ______ |
| Paved Shoulder | ____ | ______ | ______ |
| Unpaved Shoulder | ____ | ______ | ______ |
| $C_M$ = Total Cost of Lane and Shoulder Improvements Per Mi = (Sum Values in Column C) | | | ______ |

Cost for Lane and Shoulder Improvements for the Curve Length =

$C_{LS} = C_M \times L$ = $________ x ________mi = $__________

Figure 5. Worksheet for computing curve improvement costs (form C).

FORM C - CURVE IMPROVEMENT COSTS (Continued)

Step 5 - Determine Cost for Roadside Improvements

Roadside Improvement = ________________________________________

________________________________________________________

Cost for obstacle improvements (from table 10 and/or 11) = $______ $=C_{R1}$

Sideslope before condition = ______ After condition = ______

Height of fill = _____ ft

Cost for Sideslope flattening =

Cost per mi (from table 12) x (curve length) (No. of sides to be flattened) = ________ x ________ x ________ = ________ $= C_{R2}$

Total Cost for Roadside Improvements = $C_{R1} + C_{R2}$

= ________ + ________ = _________

Step 6 - Compute Total Cost of This Alternative

CT = Cost for [Step 1 =________] + [Step 2 =________] + [Step 3 =________]

+ [Step 4 =________] + [Step 5 =________] = $__________ $= C_T$

Step 7 - Compute the Annualized Cost

Annualized Cost = $C_A = C_T$ x CRF

= $__________ x __________ = __________

where CRF = Capital Recovery Factor (from table 13) based

service life (=_________) and interest rate (= _________)

Figure 5. Worksheet for computing curve improvement costs (form C). (continued)

## Step 3 - Determine the Added Cost for Upgrading Superelevation

Since superelevation in the example is not deficient, no cost is needed for upgrading. However, if superelevation were not sufficient, the added cost of paving material should be determined above and beyond the normal cost of the 3R (e.g., resurfacing) project and included.

## Step 4 - Compute the Cost for Lane and Shoulder Widening

To compute the cost of widening, we need to know the length of the new curve (L). As discussed previously,

$$
\begin{aligned}
L &= (I) \div [(D)(52.8)] \\
&= (30) \div [(5)(52.8)] \\
&= .1136 \text{ mi } (= 600 \text{ ft})
\end{aligned}
$$

The values in step 4 are completed in table 13 below for widening 10-ft lanes to 12 ft and adding 4-ft gravel shoulders (rolling terrain):

Table 13. Example calculations of costs for lane and shoulder widening (on form C).

| | Column A | Column B | Column C |
|---|---|---|---|
| Type of Widening | Amount of Widening (ft) Each Side | Cost per ft (from table 9) | Column A x Column B |
| Lane | 1 | $50,000 | $50,000 |
| Paved Shoulder | 0 | -- | -- |
| Unpaved Shoulder | 8 | $13,250 | $106,000 |
| Total Cost (Sum Values in Col. C of Lane + Shoulder Improvements Per Mi | | | $156,000 |

For a length of .1136 mi, the cost of lane and shoulder widening on the curve would be ($156,000) x (.1136 mi) = $17,720.

## Step 5 - Determine Cost for Roadside Improvements

The cost for sideslope flattening is given in table 12 for one side of the road only. Flattening a 2:1 sideslope to 4:1 on each side of the road with a 4-ft height of fill will cost $38,100 per mi. Since the curve length is .1136 mi, the estimated cost would be (.1136 mi)($38,100/mi) x (2 sides of the road) = $8,660.

The cost for cutting down 50 trees is the cost per tree (using median costs in table 10) = ($220/tree) x (50 trees) = $11,000. Thus, the total cost for roadside improvements in Step 5 = $8,660 + $11,000 = $19,660.

## Step 6 - Compute Total Cost of This Alternative

The sum of the costs in steps 1 through 5 = $C_T$ = ($212,900) + ($0) + ($0) + ($17,720) + ($19,660) = $250,280, for all of the improvements. Approximately 85 percent of this cost was for the curve flattening alone.

## Step 7 - Compute the Annualized Cost

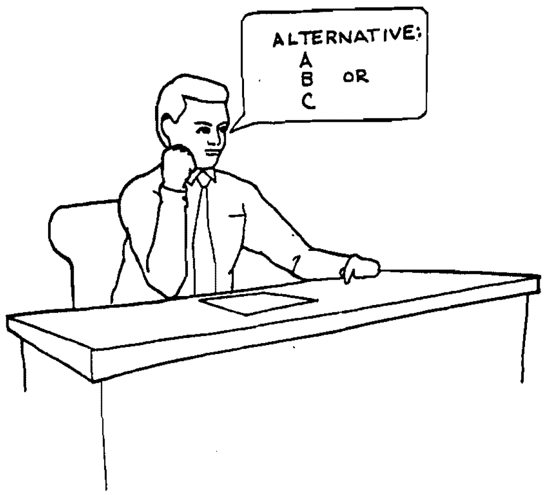
The final step in the cost calculations is to convert the present worth cost to an annual basis. This involves selecting a capital recovery factor (CRF) from table 14 and multiplying it times the total cost ($C_T$). Assuming a 20 year service life and a 6 percent interest rate, the CRF = .0872 from table 14. Thus, the annualized cost = $C_A$ = ($C_T$)(CRF) = ($250,000)(.0872) = $21,820.

The annualized cost is used in the next chapter along with the annual accident benefit to conduct an economic analysis of project alternatives.

Table 14. Factors for annual compounding of interest.[14]

| Interest Rate (Percent) | Service Life (Years) | Capital Recovery Factor, CRF | Sinking Fund Factor, SFF |
|---|---|---|---|
| 4 | 1 | 1.0400 | 1.0000 |
| | 2 | 0.5302 | 0.4902 |
| | 3 | 0.3604 | 0.3204 |
| | 4 | 0.2755 | 0.2355 |
| | 5 | 0.2246 | 0.1846 |
| | 10 | 0.1233 | 0.0833 |
| | 15 | 0.0899 | 0.0499 |
| | 20 | 0.0736 | 0.0336 |
| | 25 | 0.0640 | 0.0240 |
| 6 | 1 | 1.0600 | 1.0000 |
| | 2 | 0.5454 | 0.4854 |
| | 3 | 0.3741 | 0.3141 |
| | 4 | 0.2886 | 0.2286 |
| | 5 | 0.2374 | 0.1774 |
| | 10 | 0.1359 | 0.0759 |
| | 15 | 0.1030 | 0.0430 |
| | 20 | 0.0872 | 0.0272 |
| | 25 | 0.0782 | 0.0182 |
| 8 | 1 | 1.0800 | 1.0000 |
| | 2 | 0.5608 | 0.4808 |
| | 3 | 0.3880 | 0.3080 |
| | 4 | 0.3019 | 0.2219 |
| | 5 | 0.2505 | 0.1705 |
| | 10 | 0.1490 | 0.0690 |
| | 15 | 0.1168 | 0.0368 |
| | 20 | 0.1018 | 0.0218 |
| | 25 | 0.0937 | 0.0137 |
| 10 | 1 | 1.1000 | 1.0000 |
| | 2 | 0.5762 | 0.4762 |
| | 3 | 0.4021 | 0.3021 |
| | 4 | 0.3155 | 0.2155 |
| | 5 | 0.2638 | 0.1638 |
| | 10 | 0.1628 | 0.0628 |
| | 15 | 0.1315 | 0.0315 |
| | 20 | 0.1175 | 0.0175 |
| | 25 | 0.1102 | 0.0102 |
| 12 | 1 | 1.1200 | 1.0000 |
| | 2 | 0.5917 | 0.4717 |
| | 3 | 0.4163 | 0.2963 |
| | 4 | 0.3292 | 0.2092 |
| | 5 | 0.2774 | 0.1574 |
| | 10 | 0.1770 | 0.0570 |
| | 15 | 0.1468 | 0.0268 |
| | 20 | 0.1339 | 0.0139 |
| | 25 | 0.1275 | 0.0075 |

# CHAPTER 6 - ECONOMIC ANALYSIS PROCEDURES FOR DETERMINING PROJECT COST-EFFECTIVENESS




This chapter allows the user to either compare the economic consequences of two or more project alternatives at a horizontal curve site or to compare project alternatives at two or more locations. Several economic inputs are needed to conduct the cost-effectiveness analysis, including:

- Project Service Life: For each curve improvement under consideration, service life must be estimated for use in computing accident benefits. A service life of 20 years is often regarded as a reasonable assumption for most "permanent" types of curve geometric improvements such as curve flattening, roadway widening, sideslope flattening, and adding a spiral transition. However, service lives of 5 to 15 years may be more appropriate for upgrading of superelevation, which may change through pavement settling and future resurfacing.
- Salvage Value: The salvage value is the dollar value of a project at the end of its service life. For most widening projects, the salvage value is very small and generally assumed to be zero.
- Interest Rate: The interest rate of money is an important input in the cost-effectiveness procedure. Different interest rates can affect the selection of a particular improvement

alternative in many cases. Interest rates used by agencies vary widely. The user should select an interest rate that reflects the policy of the particular agency, although interest rates of 4 to 12 percent are commonly used.

Numerous economic analysis methods are available for use in selecting project alternatives, including the simple benefit-to-cost ratio method, incremental benefit-to-cost ratio method, net benefit method, rate of return method, time of return method, and others. Some of the examples and information in this chapter were taken from the users manuals on utility pole accidents and cross-section improvements.(15,16) Agencies should use their own preferred method(s) for conducting economic analyses. For purposes of illustration in this Informational Guide, however, the benefit-to-cost ratio and the incremental benefit-to-cost ratio methods involve the following steps:

Step 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the Benefit-to-Cost Ratio (B/C)

The B/C ratio for the project is the total benefits divided by the total project costs as follows:

$$B/C = \text{Benefit-to-cost ratio for the improvement} = \frac{B_T}{C_T}$$

where

$B_T$ = Total accident benefits per year.
$C_T$ = Total countermeasure costs per year.

The B/C ratio should be computed separately for each project alternative using figure 6 (form D) for up to 5 project alternatives per location. The benefits and costs, may both be expressed on a per year basis or on a present worth basis (with the same B/C ratio).

Of these economic measures, any one of them is appropriate for determining the economic feasibility of a given project (e.g., the B/C ratio is 2.3, the net benefit is $120,000, the rate of return is 22 percent per year, etc.). However, when comparing between two or more alternatives, the simple B/C ranking of projects often does not give the best economic results. Consider, for example, four improvement alternatives at a horizontal curve:

## FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are Being Considered at the Same Location)

**STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio**

| Rank | Column A<br>Improve-ment Number | Column B<br>Total Annual Cost ($C_T$) | Column C<br>Total Annual Benefits ($B_T$) | Column D<br>B/C Ratio | Column E<br>Compare | Column F<br>Incremental Change in Costs ( C) | Column G<br>Incremental Change in Benefits ( B) | Column H<br>Incremental Benefit/ Cost Ratio B/ C |
|---|---|---|---|---|---|---|---|---|
| Lowest Cost (CT) | | | | | | | | |
| 2nd Lowest Cost | | | | | | | | |
| 3rd Lowest Cost | | | | | | | | |
| 4th Lowest Cost | | | | | | | | |
| Highest Cost | | | | | | | | |

**STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)**

Complete Columns E, F, G. and H in step 1.

**STEP 3 - Evaluate Available Funding and Other Agency Constraints**

Select improvement with the highest incremental benefits to highest incremental costs:

Improvement No. and Description: ________________________________

________________________________________________

________________________________________________

Improvement Cost: $________________ per year

Is funding available to complete project (Yes or No) ________

Do any other agency constraints prohibit implementation (Yes or No)

________

If Yes, Describe: ________________________________

Will all curve design guidelines meet with each project alternative?

________

If not, give details ________________________________

________________________________________________

Figure 6. Worksheet for comparison of project alternatives (form D).

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

Improvement No. and Description: ______________________

Improvement Cost: $______________ per year

STEP 4 - Record Project Details

Selected Improvement: ______________________________

Project Cost: $______________ per year

Total Project Cost: $______________

Change in Annual Maintenance Costs: $______________

Accidents Reduced per Year: ______________

Annual Accident Benefits: $______________

B/C Ratio = __________

Comments: ______________________________

__________________________________________

__________________________________________

__________________________________________

Figure 6. Worksheet for comparison of project alternatives (form D)(continued).

options A, B, C, and D. Consider the benefits and costs of each option as shown in table 15.

Table 15. Summary of benefits and costs for four project alternatives.

| Option | Column 1 Annual Costs | Column 2 Annual Benefits | Column 3 Net Benefits (B-C) | Column 4 B/C Ratio |
|---|---|---|---|---|
| A | $21,260 | $40,800 | $19,540 | 1.9 |
| B | $ 1,510 | $15,200 | $13,690 | 10.1 |
| C | $ 1,710 | $12,800 | $11,090 | 7.5 |
| D | $24,500 | $52,800 | $28,300 | 2.2 |

In this example, the priority of alternatives based on the simple benefit-to-cost ratio method (column 4) would be B, C, D, and A. It should be noted that a priority ranking based on the simple B/C ratio will usually result in selecting the lower-cost options (as in this case), while the simple net benefit method (column 3) usually results in selecting one of the higher cost options (alternative D or A). However, as mentioned previously, a simple ranking of projects by B/C ratio or net benefits is not considered adequate. The most economically desirable solutions overall can be found using the incremental benefit-to-cost ratio method, as discussed below.

Step 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\nabla B/\nabla C$)

The incremental benefit-to-cost ratio method can be used to determine whether extra increments of cost (e.g., widening the curve plus roadside improvements vs. curve widening only) are justified for a particular location or for considering improvements at two or more locations. The method assumes that the relative merit of a project is measured by its change in benefits and costs, compared to the next lower-cost alternative.

The steps for using the incremental benefit-to-cost ratio method are given below, as discussed in the "Highway Safety Improvement Program" manual: (17)

1. Determine the benefits, costs and the resulting benefit-to-cost ratio for each improvement.

2. List improvements with a B/C ratio greater than 1 (or some other minimum value) in order of increasing cost.

3. Calculate the incremental B/C ratio of the second lowest-cost improvement compared to the lowest cost improvement.

4. Continue in order of increasing costs, to calculate the incremental B/C ratio for each improvement compared to the next lower cost improvement.

5. Stop when the incremental B/C ratio is less than 1.0.

To illustrate the use of this method, consider the costs and benefits in table 16 based on the example given previously. Note that options which must be ordered from lowest to highest cost.

Table 16. Illustration of incremental benefit-cost analysis.

| Option | Annual Benefits | Annual Costs | B/C Ratio | Comparison of Options | Incremental Benefits | Incremental Costs | Incremental Benefit/Cost Ratio ($\Delta B/\Delta C$) |
|---|---|---|---|---|---|---|---|
| B | $15,200 | $1,510 | 10.1 | B and C | $-2,400 | $200 | -12.0 (Pick B) |
| C | $12,800 | $1,710 | 7.5 | B and A | $25,600 | $19,750 | 1.3 (Pick A) |
| A | $40,800 | $21,260 | 1.9 | A and D | $12,000 | $3,240 | 3.7 (Pick D) |
| D | $52,800 | $24,500 | 2.2 | | | | |

From this example, option B (lowest cost option) is first compared with option C, and option B is preferred to option C ($\Delta B/\Delta C$ = -12.0). Option C is then excluded from further consideration. Option B is next compared with option A, and option A (the higher cost option) is preferred, since $\Delta B/\Delta C$ = 1.3 (greater than 1.0). In this case, spending an additional $19,750 on Option A will yield $25,600 of additional benefits. Option B is then eliminated from further consideration. Finally, options A and D are compared, and the additional $3,240 in cost from option D is compared with the $12,000 of additional benefits from option D. Thus, $\Delta B/\Delta C$ = 3.7 between options D and A, and option D is the optimal solution based on incremental benefits and costs. Notice that option D was selected with a simple B/C ratio of 2.2, even though options B and C had B/C ratios of 10.1 and 7.5, respectively. This solution would, of course, be subject to funding availability, political considerations, environmental constraints, etc.

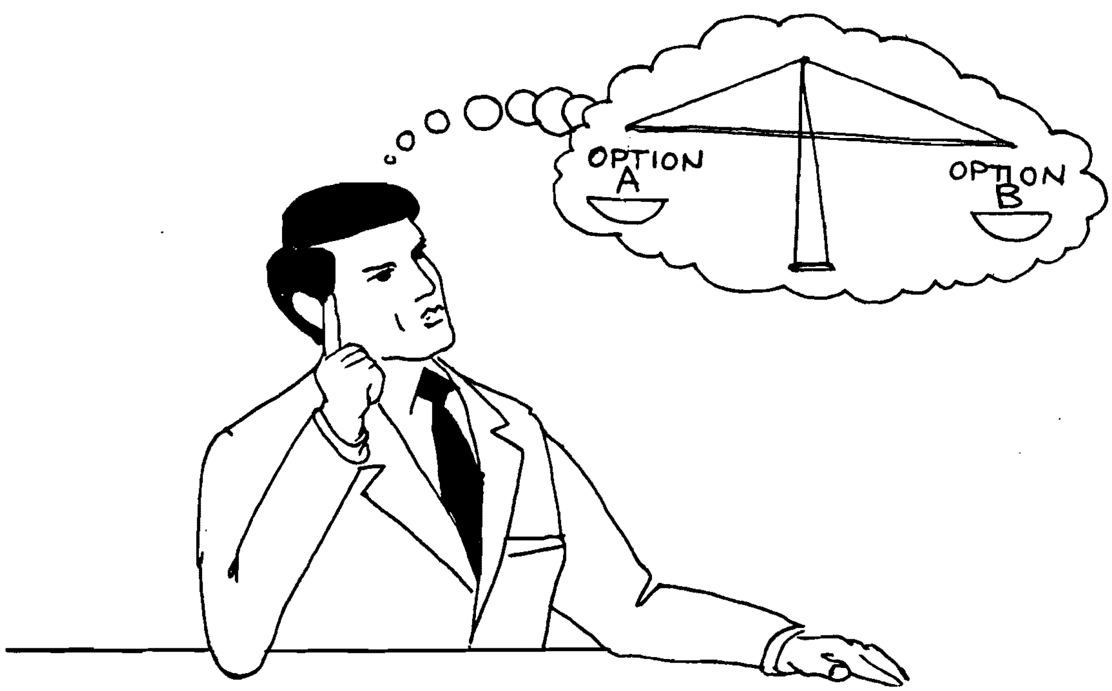
Step 3 - Evaluate Available Funding and Other Agency Constraints

This step involves summarizing critical details for the selected project alternative, such as:

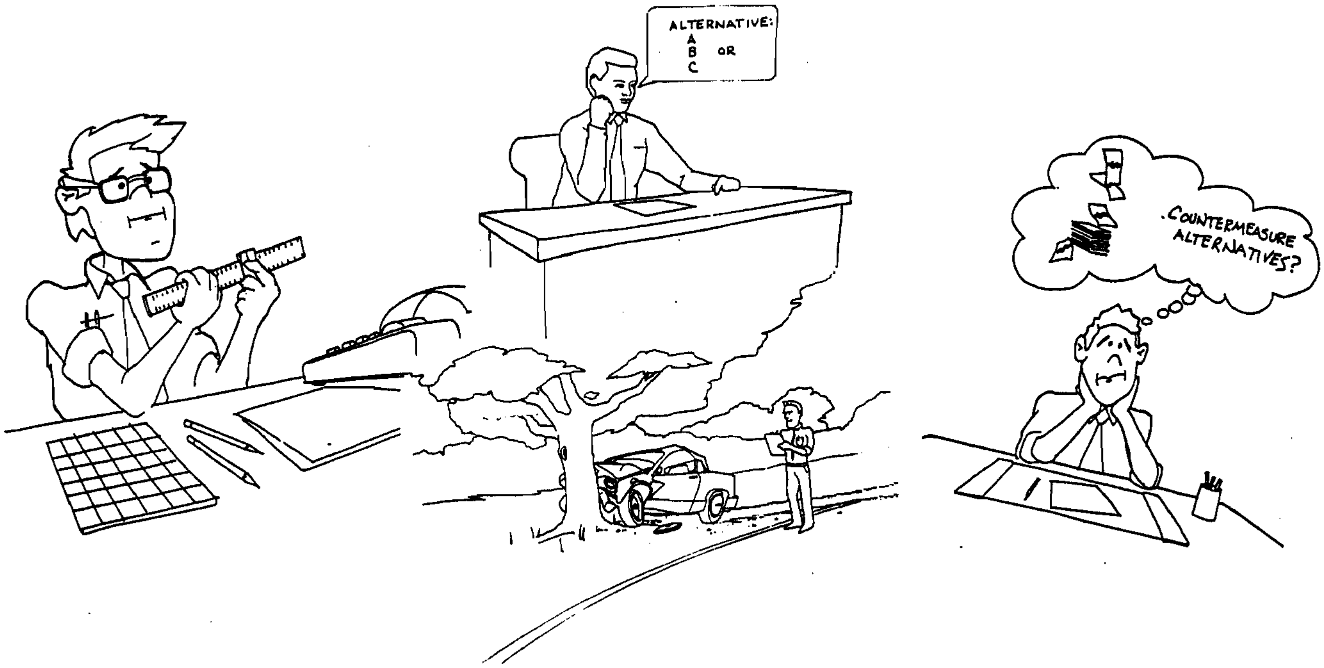
- The improvement cost.
- Whether sufficient funding is available to complete the project.
- A listing of other considerations (such as environmental considerations, effect on highway capacity and operations, need for additional right-of-way, etc.) These and other factors need to be considered which could affect the practical implementation of the project.

Step 4 - Record Project Details

The project details of the selected countermeasure should be documented (see, for example, form B). This will be useful for future project planning and implementation as well as for conducting cost-effectiveness evaluations at other sites. Copies of the blank worksheets are given in appendix A.



# CHAPTER 7 - CASE STUDY




The following is a worked out example of the calculation of accident benefits and project costs for three improvement alternatives at a horizontal curve. Portions of this example were discussed within chapters 4 and 5. The completed forms A through D are given, including separate form B's and form C's for each project alternative.

## Existing Conditions

A horizontal curve on a collector roadway was under review for possible safety improvements as part of a 3R project. The existing geometric, roadway, traffic, and accident information for the curve were as follows:

- Degree of curve (D) = 10 degrees.
- Central angle = 30 degrees.
- No spirals exist.
- Superelevation is adequate, i.e., the actual superelevation, $e_A$ = .08 and the desired superelevation, $e_R$ (from the AASHTO Greenbook) = .078.
- Roadway width = 20 ft (i.e., two 10-ft lanes with no shoulders).
- Rolling terrain.
- ADT = 1,750.
- Approach tangent lengths = 1,200 ft and 1,650 ft.
- Sideslope = 2:1, roadside recovery distance = 5 ft (with trees on the roadside).

- Curve length (L) = (I) ÷ [(D)(52.8)]
  = .057 mi = 300 ft.
- Accident experience = 4 total accidents in the past 5 years, including one head-on, one rollover, and two fixed-object (i.e., hit tree). Of the 4 accidents, 2 of them occurred at night.

## Proposed Alternatives

Four separate improvement alternatives were considered for reducing crashes on the curve. These alternatives include:

### Alternative A

- Flatten the 10-degree curve to 5 degrees.
- Add a spiral of 300 ft to each end of the curve.
- Widen the 10-ft lanes to 11 ft and add an 8-ft unpaved shoulder.
- Flatten the sideslope on the inside and outside of the curve from 2:1 to 4:1 (4 ft height of fill) plus remove 50 trees currently located between 54 and 20 ft from the road (i.e., an increase in roadside recovery distance from 5 to 20 ft).

### Alternative B

- Widen the 10-ft lanes to 12 ft and add 6-ft paved shoulders.
- Flatten the sideslope from 2:1 to 4:1 and remove 50 trees to create a 20-ft roadside recovery distance (similar to that described for Alternative A above).

### Alternative C

- Flatten the 10-degree curve to 5 degrees.
- Add a spiral of 300 ft to each end of the curve.
- Widen the 10-ft lanes to 12 ft and add 8-ft paved shoulders.
- Flatten the sideslope from 2:1 to 6:1 and remove 70 trees to create a 25-ft roadside recovery distance.

## Assumptions

Some of the assumptions made in the analysis include:

- A traffic growth rate of 2 percent per year.
- A 20 year service life on all improvements.
- A cost of $59,000 per curve accident (as recommended in chapter 4)

- A 6 percent rate of interest.
- Cost of removing trees is the median level from table 9 (i.e., \$220 per tree removed).
- No additional right-of-way costs were required for any of the proposed improvements.

## Solution

The site conditions are given on form A. A separate form B and form C is given for each of the three project alternatives. Form D summarizes the B/C ratio and the incremental B/C ratio analysis.

Annual benefits and costs were computed for each alternative. The simple benefit-cost ratio was highest for alternative B (B/C = 6.6), which was the lowest-cost alternative (i.e., lane and shoulder widening plus roadside improvements, but no curve flattening). Benefit-cost ratios for alternative A and C were 2.0 and 1.9, respectively. Using the incremental benefit-cost ratio method, alternative B was preferred over alternative A ($\Delta B/\Delta C$ = .90) and also preferred to alternative C ($\Delta B/\Delta C$ = .94). Thus, the flattening of the curve (as proposed in alternative A and C), was not found to be justified, using strictly the results of incremental B/C ratio method. Of course, other factors should also be considered in the final decision on various roadway improvements. Also, other project alternatives involving curve flattening may likewise be analyzed to determine their economic feasibility.

The completed forms A, B, C, and D are attached which show the site characteristics (form A) calculation of benefits (form B's), cost calculation (form C's), and the incremental B/C ratio calculations of alternatives (form D). The completed form are ordered as follows:

- Site characteristics (form A).
- Alternative A
  - form B (benefit calculations).
  - form C (cost calculations).

- Alternative B
  - form B (benefit calculations).
  - form C (cost calculations).

- Alternative C
  - form B (benefit calculations).
  - form C (cost calculations).

- Incremental benefit-cost ratio (form D).

HORIZONTAL CURVE DESIGN

FORM A - CURVE SITE DESCRIPTION

1. Road Name or Route Identification: NC Route 9999

2. Curve Milepoint Beginning: 1.000 Ending: 1.057 Length: .057 (Mi)

3. Area Type (Check): ✓ Rural 300 (Ft)

   ____ Urban (If urban, procedures in this manual do not apply.)

> To convert curve radius (R) to Degrees (D):
>
> $D = \frac{5729.6}{R}$

4. Degree of curve: 10 (Degrees/100 ft of Arc)

5. Central Angle: 30 (Degrees)

6. Spiral Transitions on Curve Approaches

   ____ Yes ✓ No

7. Actual Superelevation on Curve ($e_A$): .08

8. State Superelevation Policy (check one): ___ .06 ✓ .08 ___ .10

9. Roadway Design Speed: 40 mi/h

10. AASHTO Greenbook Recommended Superelevation for this Curve: .078 ($e_R$)

11. Superelevation Deviation ($e_R$ - $e_A$): ≃ 0

12. Length of Tangent on Curve Approach: Direction 1: 1,200 Ft

    Direction 2: 1,650 Ft

13. Terrain Condition (Check One):

    ____ Flat ✓ Rolling ____ Mountainous

14. Present Average Daily Traffic ($ADT_B$): 1,750

15. Expected Annual Traffic Growth Rate = g = 2 percent per year

16. Lane Width: 10 Ft

17. Paved Shoulder Width: 0 Ft

18. Unpaved Shoulder (e.g., Dirt, Gravel, Turf, Stabilized)

    Width = 0 Ft

FORM A - CURVE SITE DESCRIPTION (Continued)

19. Typical Sideslope (Check One):

✓ 2:1, or steeper, __3:1, __4:1, __5:1, __6:1, __7:1 or flatter

20. Average Roadside Recovery Distance = 5 Ft

21. Reliable Accident Data for the Section (Check One):

✓ Available ______ Unavailable

Note: If reliable accident data are unavailable, or if no accidents have been reported at the curve in recent years, economic analysis procedures are not approximate. Review step 5A in text and chapter 2 for improvement guidelines to existing curves.

22. Total Curve Accidents = 4 for 5 years

23. Total Curve Accidents per Year Before Improvement = $A_{TB}$

$$= \frac{\text{Total Number of Curve Accidents}}{\text{Number of Years of Data}}$$

$$= 4 \div 5 = 0.8$$

24. (Optional Information): Number of Curve Accidents by Type for _____ Years

| | | | | |
|---|---|---|---|---|
| Single Vehicle (Run-Off-Road and Rollover) | = 3 | , or | 0.6 | Per Year |
| Head-On and Opposite Direction Sideswipe | = 1 | , or | 0.2 | Per Year |
| Nighttime Accidents | = 2 | , or | 0.4 | Per Year |
| Wet-Weather Accidents | = 0 | , or | 0 | Per Year |

HORIZONTAL CURVE DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Curve Location NC 9999 Alternative 1 of 3

Step 1: Complete the Curve Site Description Form Alt. A

Step 2: Complete the Following Information on the Proposed Improvement:

Description of Alternative Flatten curve to 5 degrees, Add 300-ft spirals, Widen lanes to 11 ft, Add 8-ft unpaved shoulders, Flatten sideslopes to 4:1, Remove 50 trees

| Roadway Feature | Before Treatment | After Treatment |
|---|---|---|
| Degree of Curve | 10 | 5 |
| Spiral Transitions (yes or no) | No | Yes |
| Superelevation | .08 | .08 |
| Superelevation Deviation | ≈ 0 | ≈ 0 |
| Lane Width | 10 | 11 |
| Paved Shoulder Width | 0 | 0 |
| Unpaved Shoulder Width | 0 | 8 |
| Avg. Roadside Recovery Distance | 5 | 20 |
| Typical Sideslope | 2:1 | 4:1 |

Step 3: Compute the ADT Over the Future Project Life ($ADT_F$)

ADT before improvement = 1,750 = $ADT_B$

Project service life = 20 years

Annual growth rate = g = 2 percent per year

Adjustment factor = 1.24 = $F_A$ (from table 1)

Future ADT = $ADT_F$ = ($ADT_B$) x ($F_A$) = 1,750 x 1.24 = 2,170

Step 4: Determine the Expected Number of Future Accidents per Year on the Curve Without the Improvement ($A_{UF}$)

- Step 4A: If reliable accident data are unavailable for the curve site or if no accidents have been reported at the curve in recent years, an economic analysis of project alternatives is not feasible. Do not continue past step 4, but refer to chapter 2 for guidelines on making safety improvements.

AH.A

- Step 4B: Reliable accident data are available for the curve site.

$A_{TB}$ = 0.8 Total accidents on the curve per year before treatment (from Form A)

Service life = 20

Traffic growth rate = g = 2%/yr.

$F_A$ = The factor (from table 1) to adjust current ADT to future ADT = 1.24

$A_{UF}$ = Future accidents per year in the untreated condition

= $A_{TB}$ x $F_A$ = 0.8 x 1.24 = 1.0

Step 5: Determine the Accident Reduction (AR) Factor

| Curve Improvement | Source of AR Factor |
|---|---|
| 1. Curve flattening | Table 2 |
| 2. Upgrading deficient superelevation | Table 3 |
| 3. Adding a spiral transition | Use AR factor of 5 percent for adding spirals to curve |
| 4. Lane widening | Table 4 |
| 5. Widening paved shoulder | Table 4 |
| 6. Widening unpaved shoulder | Table 4 |
| 7. Sideslope flattening | Table 5 |
| 8. Removal of roadside obstacles | Table 6 |
| 9. Combining two or more of the improvements into one project | (see Step 5B) |

Note: Pavement resurfacing is assumed to be included with improvements 1 through 6 above.

- Step 5A: Determine AR factors for individual improvement projects using tables 2 through 6, as listed above
  - Curve flattening (use table 2): AR = 48
  - Upgrade superelevation: AR = N.A.
  - Add spiral (use table 3): AR = 5
  - Lane widening only (use table 4): AR = 5
  - Shoulder widening only (use table 4): AR = 24
  - Roadside improvements (use tables 5 and/or 6): AR = 23

 Alt. A

(Note: If curve flattening plus other roadside improvements are proposed for the same alternative, use table 6 for estimating the combined effects of roadside improvements.)

- Step 5B: Combine Individual AR Factors

Overall accident reduction (AR) from more than one improvement:

$$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)(1 - AR_5) \ldots$$
$$= 1 - (1 - .48)(1 - .05)(1 - .05)(1 - .24)(1 - .23) = .725 \text{ or } .72$$

where:

$AR_1$, $AR_2$ and $AR_3$, etc. are accident reduction factors for improvements 1, 2, 3, etc., respectively

Step 6: Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)
The net number of total curve accidents reduced per year ($\Delta A$) is computed as follows:

$$\Delta A = (A_{UF}) \times (AR)$$

where:

$A_{UF}$ = future accidents per year in the untreated condition (from step 4B)

AR = combined accident reduction factor (from step 5B).

Thus, $\Delta A = A_{UF} \times AR$ = 1.0 x .72 = .72 accidents reduced per year

Step 7: Determine the Average Cost per Curve Accident ($C_A$)

$C_A$ = $ 59,000 (Use $59,000 if unknown)

Step 8: Compute the Expected Annual Accident Benefits ($B_A$)

$B_A$ = accident benefits per year based on the net reduction in curve accidents

$(\Delta A) \times (C_A)$ = .72 x $ 59,000 = $ 42,480

where,

$\Delta A$ = net reduction in accidents per year (see step 6)

$C_A$ = average cost of a curve accident (see step 7)

HORIZONTAL CURVE DESIGN

FORM C - CURVE IMPROVEMENT COSTS

(Complete One of These Forms for Each Project Alternative)

Curve Location N. C. 9999 Alternative No. 1 of 3

Improvement Project(s) Included as Part of this Alternative: Alt. A

1. Flatten curve to 5 degrees 2. Add 300-ft spirals
3. Widen lanes to 11 ft 4. Add 8-ft unpaved shoulders
5. Flatten sideslope to 4:1 6. Remove 50 trees

Step 1 - Determine Cost for Curve Flattening.

Degree of curve before flattening = 10 after flattening = 5
Central angle = 30

Estimated cost for flattening (from table 8) = $ 212,900

Step 2 - Estimate the Additional Cost for Adding Spirals.

Length of each spiral (from AASHTO Greenbook) = 300 ft
Estimated cost for adding spiral = $ ≈ 0

Step 3 - Determine the Added Cost for Upgrading Superelevation.

Cost for superelevation upgrading = $ N.A.

Step 4 - Compute Cost for Lane and Shoulder Widening.

Curve Length (L) = .1136 mi

| Type of Widening | Column A<br>Amount of Widening in ft (Each Side) | Column B<br>Cost per foot (From table 9) | Column C<br>Column A x Column B |
|---|---|---|---|
| Lane | 1 | $ 50,000 | $ 50,000 |
| Paved Shoulder | 0 | — | — |
| Unpaved Shoulder | 8 | $ 13,250 | $ 106,000 |
| $C_M$ = Total Cost of Lane and Shoulder Improvements Per Mi = (Sum Values in Column C) | | | $ 156,000 |

Cost for Lane and Shoulder Improvements for the Curve Length =

$C_{LS} = C_M \times L$ = $ 156,000 x .1136 mi = $ 17,720

 Alt. A

Step 5 - Determine Cost for Roadside Improvements

Roadside Improvement = Remove 50 trees

Flatten sideslope from 2:1 to 4:1

Cost for obstacle improvements (from table 10 and/or 11) = $ 11,000 = $C_{R1}$

Sideslope before condition = 2:1 After condition = 4:1

Height of fill = 4 ft

Cost for Sideslope flattening =

Cost per mi (from table 12) x (curve length) (No. of sides to be flattened) = $38,100 x .1136 x 2 = $8660 = $C_{R2}$

Total Cost for Roadside Improvements = $C_{R1} + C_{R2}$

= $11,000 + $8660 = $19,660

Step 6 - Compute Total Cost of This Alternative

CT = Cost for [Step 1 = $212,900] + [Step 2 = $0] + [Step 3 = $0]
+ [Step 4 = $17,720] + [Step 5 = $19,660] = $ 250,280 = $C_T$

Step 7 - Compute the Annualized Cost

Annualized Cost = $C_A = C_T \times CRF$

= $ 250,280 x .0872 = 21,820

where CRF = Capital Recovery Factor (from table 13) based service life (= 20) and interest rate (= 6%)

HORIZONTAL CURVE DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Curve Location NC 9999 Alternative 2 of 3

Step 1: Complete the Curve Site Description Form Alt. B

Step 2: Complete the Following Information on the Proposed Improvement:

Description of Alternative Widen lanes to 12 ft, Add 6-ft paved shoulders, Flatten sideslope to 4:1, and Remove 50 trees

| Roadway Feature | Before Treatment | After Treatment |
|---|---|---|
| Degree of Curve | 10 | 10 |
| Spiral Transitions (yes or no) | No | No |
| Superelevation | .08 | .08 |
| Superelevation Deviation | ≈ 0 | ≈ 0 |
| Lane Width | 10 | 12 |
| Paved Shoulder Width | 0 | 6 |
| Unpaved Shoulder Width | 0 | 0 |
| Avg. Roadside Recovery Distance | 5 | 20 |
| Typical Sideslope | 2:1 | 4:1 |

Step 3: Compute the ADT Over the Future Project Life ($ADT_F$)

ADT before improvement = 1,750 = $ADT_B$

Project service life = 20 years

Annual growth rate = g = 2 percent per year

Adjustment factor = 1.24 = $F_A$ (from table 1)

Future ADT = $ADT_F$ = ($ADT_B$) x ($F_A$) = 1,750 x 1.24 = 2,170

Step 4: Determine the Expected Number of Future Accidents per Year on the Curve Without the Improvement ($A_{UF}$)

- Step 4A: If reliable accident data are unavailable for the curve site or if no accidents have been reported at the curve in recent years, an economic analysis of project alternatives is not feasible. Do not continue past step 4, but refer to chapter 2 for guidelines on making safety improvements.

FORM B - ACCIDENT BENEFITS CALCULATION (Continued)

Att. B

- Step 4B: Reliable accident data are available for the curve site.

$A_{TB}$ = 0.8 Total accidents on the curve per year before treatment (from Form A)

Service life = 20

Traffic growth rate = g = 2 %/yr.

$F_A$ = The factor (from table 1) to adjust current ADT to future ADT = 1.24

$A_{UF}$ = Future accidents per year in the untreated condition

$= A_{TB} \times F_A =$ 0.8 x 1.24 = 1.0

Step 5: Determine the Accident Reduction (AR) Factor

| Curve Improvement | Source of AR Factor |
|---|---|
| 1. Curve flattening | Table 2 |
| 2. Upgrading deficient superelevation | Table 3 |
| 3. Adding a spiral transition | Use AR factor of 5 percent for adding spirals to curve |
| 4. Lane widening | Table 4 |
| 5. Widening paved shoulder | Table 4 |
| 6. Widening unpaved shoulder | Table 4 |
| 7. Sideslope flattening | Table 5 |
| 8. Removal of roadside obstacles | Table 6 |
| 9. Combining two or more of the improvements into one project | (see Step 5B) |

Note: Pavement resurfacing is assumed to be included with improvements 1 through 6 above.

- Step 5A: Determine AR factors for individual improvement projects using tables 2 through 6, as listed above
  - Curve flattening (use table 2): AR = N.A.
  - Upgrade superelevation: AR = N.A.
  - Add spiral (use table 3): AR = N.A.
  - Lane widening only (use table 4): AR = 12
  - Shoulder widening only (use table 4): AR = 21
  - Roadside improvements (use tables 5 and/or 6): AR = 23

(Note: If curve flattening plus other roadside improvements are proposed for the same alternative, use table 6 for estimating the combined effects of roadside improvements.)

- Step 5B: Combine Individual AR Factors

Overall accident reduction (AR) from more than one improvement:

$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)(1 - AR_5)\ .....$
$= 1 - (1 - .12)(1 - .21)(1 - .23)(1 - \_\_)(1 - \_\_) = .46$

where:

$AR_1$, $AR_2$ and $AR_3$, etc. are accident reduction factors for improvements 1, 2, 3, etc., respectively

Step 6: Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)
The net number of total curve accidents reduced per year ($\Delta A$) is computed as follows:

$$\Delta A = (A_{UF}) \times (AR)$$

where:

$A_{UF}$ = future accidents per year in the untreated condition (from step 4B)

AR = combined accident reduction factor (from step 5B).

Thus, $\Delta A = A_{UF} \times AR = 1.0 \times .46 = .46$ accidents reduced per year

Step 7: Determine the Average Cost per Curve Accident ($C_A$)

$C_A$ = $ 59,000 (Use $59,000 if unknown)

Step 8: Compute the Expected Annual Accident Benefits ($B_A$)

$B_A$ = accident benefits per year based on the net reduction in curve accidents

$(\Delta A) \times (C_A)$ = .46 x $ 59,000 = $ 27,140

where,

$\Delta A$ = net reduction in accidents per year (see step 6)

$C_A$ = average cost of a curve accident (see step 7)

HORIZONTAL CURVE DESIGN

FORM C - CURVE IMPROVEMENT COSTS

(Complete One of These Forms for Each Project Alternative)

Curve Location NC 9999 Alternative No. 2 of 3

Improvement Project(s) Included as Part of this Alternative: Alt. B

1. Widen lanes to 12 ft 2. Add 6-ft paved shoulders

3. Flatten sideslopes to 4:1 4. Remove 50 trees

5. ______ 6. ______

Step 1 - Determine Cost for Curve Flattening. N.A.

Degree of curve before flattening = ______ after flattening = ______
Central angle = ______

Estimated cost for flattening (from table 8) = $______

Step 2 - Estimate the Additional Cost for Adding Spirals. N.A.

Length of each spiral (from AASHTO Greenbook) = ______
Estimated cost for adding spiral = $______

Step 3 - Determine the Added Cost for Upgrading Superelevation.

Cost for superelevation upgrading = $______ N.A.

Step 4 - Compute Cost for Lane and Shoulder Widening.

Curve Length (L) = .1136 mi

| Type of Widening | Column A<br>Amount of Widening in ft (Each Side) | Column B<br>Cost per foot (From table 9) | Column C<br>Column A x Column B |
|---|---|---|---|
| Lane | 2 | $ 50,000 | $ 100,000 |
| Paved Shoulder | 6 | $ 23,750 | $ 142,500 |
| Unpaved Shoulder | 0 | — | — |
| $C_M$ = Total Cost of Lane and Shoulder Improvements Per Mi = (Sum Values in Column C) | | | $ 242,500 |

Cost for Lane and Shoulder Improvements for the Curve Length =

$C_{LS} = C_M \times L$ = $ 242,500 x .1136 mi = $ 21,550

FORM C - CURVE IMPROVEMENT COSTS (Continued)

Alt. B

Step 5 - Determine Cost for Roadside Improvements

Roadside Improvement = Remove 50 trees

Flatten sideslope from 2:1 to 4:1

Cost for obstacle improvements (from table 10 and/or 11) = $ 11,000 = $C_{R1}$

Sideslope before condition = 2:1 After condition = 4:1

Height of fill = 4 ft

Cost for Sideslope flattening =

Cost per mi (from table 12) x (curve length) (No. of sides to be flattened) = 38,100 x .1136 x 2 = $8,660 = $C_{R2}$

Total Cost for Roadside Improvements = $C_{R1}$ + $C_{R2}$

= $11,000 + $8,660 = $19,660

Step 6 - Compute Total Cost of This Alternative

CT = Cost for [Step 1 = $ 0 ] + [Step 2 = $ 0 ] + [Step 3 = $ 0 ]

+ [Step 4 = $ 27,550 ] + [Step 5 = $ 19,660 ] = $ 47,210 = $C_T$

Step 7 - Compute the Annualized Cost

Annualized Cost = $C_A$ = $C_T$ x CRF

= $ 47,210 x .0872 = $4,117

where CRF = Capital Recovery Factor (from table 13) based

service life (= 20 ) and interest rate (= 6% )

HORIZONTAL CURVE DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Curve Location NC 9999 Alternative 3 of 3

Step 1: Complete the Curve Site Description Form Alt. C

Step 2: Complete the Following Information on the Proposed Improvement:

Description of Alternative Flatten curve to 5 degrees, Add 300-Ft spirals, widen lanes to 12 Ft, Add 8-Ft paved shoulders, Flatten sideslope to 6:1, and Remove 70 trees

| Roadway Feature | Before Treatment | After Treatment |
|---|---|---|
| Degree of Curve | 10 | 5 |
| Spiral Transitions (yes or no) | No | Yes |
| Superelevation | .08 | .08 |
| Superelevation Deviation | ≈0 | ≈0 |
| Lane Width | 10 | 12 |
| Paved Shoulder Width | 0 | 8 |
| Unpaved Shoulder Width | 0 | 0 |
| Avg. Roadside Recovery Distance | 5 | 25 |
| Typical Sideslope | 2:1 | 4:1 |

Step 3: Compute the ADT Over the Future Project Life ($ADT_F$)

ADT before improvement = 1,750 = $ADT_B$

Project service life = 20 years

Annual growth rate = g = 2 percent per year

Adjustment factor = 1.24 = $F_A$ (from table 1)

Future ADT = $ADT_F$ = ($ADT_B$) x ($F_A$) = 1,750 x 1.24 = 2,170

Step 4: Determine the Expected Number of Future Accidents per Year on the Curve Without the Improvement ($A_{UF}$)

- Step 4A: If reliable accident data are unavailable for the curve site or if no accidents have been reported at the curve in recent years, an economic analysis of project alternatives is not feasible. Do not continue past step 4, but refer to chapter 2 for guidelines on making safety improvements.

 Alt. C

- Step 4B: Reliable accident data are available for the curve site.

$A_{TB}$ = 0.8 Total accidents on the curve per year before treatment (from Form A)

Service life = 20

Traffic growth rate = g = 2%/yr.

$F_A$ = The factor (from table 1) to adjust current ADT to future ADT = 1.24

$A_{UF}$ = Future accidents per year in the untreated condition

$= A_{TB} \times F_A$ = 0.8 x 1.24 = 1.0

Step 5: Determine the Accident Reduction (AR) Factor

| Curve Improvement | Source of AR Factor |
|---|---|
| 1. Curve flattening | Table 2 |
| 2. Upgrading deficient superelevation | Table 3 |
| 3. Adding a spiral transition | Use AR factor of 5 percent for adding spirals to curve |
| 4. Lane widening | Table 4 |
| 5. Widening paved shoulder | Table 4 |
| 6. Widening unpaved shoulder | Table 4 |
| 7. Sideslope flattening | Table 5 |
| 8. Removal of roadside obstacles | Table 6 |
| 9. Combining two or more of the improvements into one project | (see Step 5B) |

Note: Pavement resurfacing is assumed to be included with improvements 1 through 6 above.

- Step 5A: Determine AR factors for individual improvement projects using tables 2 through 6, as listed above
  - Curve flattening (use table 2): AR = 48
  - Upgrade superelevation: AR = N.A.
  - Add spiral (use table 3): AR = 5
  - Lane widening only (use table 4): AR = 12
  - Shoulder widening only (use table 4): AR = 28
  - Roadside improvements (use tables 5 and/or 6): AR = 29

 Alt. C

(Note: If curve flattening plus other roadside improvements are proposed for the same alternative, use table 6 for estimating the combined effects of roadside improvements.)

- Step 5B: Combine Individual AR Factors

Overall accident reduction (AR) from more than one improvement:

$$AR = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)(1 - AR_5) \ldots\ldots$$
$$= 1 - (1 - .48)(1 - .05)(1 - .12)(1 - .28)(1 - .29) = .78$$

where:

$AR_1$, $AR_2$ and $AR_3$, etc. are accident reduction factors for improvements 1, 2, 3, etc., respectively

Step 6: Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)
The net number of total curve accidents reduced per year ($\Delta A$) is computed as follows:

$$\Delta A = (A_{UF}) \times (AR)$$

where:

$A_{UF}$ = future accidents per year in the untreated condition (from step 4B)

$AR$ = combined accident reduction factor (from step 5B).

Thus, $\Delta A = A_{UF} \times AR$ = 1.0 x .78 = .78 accidents reduced per year

Step 7: Determine the Average Cost per Curve Accident ($C_A$)

$C_A$ = $59,000 (Use $59,000 if unknown)

Step 8: Compute the Expected Annual Accident Benefits ($B_A$)

$B_A$ = accident benefits per year based on the net reduction in curve accidents

$(\Delta A) \times (C_A)$ = .78 x $59,000 = $46,020

where,

$\Delta A$ = net reduction in accidents per year (see step 6)

$C_A$ = average cost of a curve accident (see step 7)

HORIZONTAL CURVE DESIGN

FORM C - CURVE IMPROVEMENT COSTS

(Complete One of These Forms for Each Project Alternative)

Curve Location N.C. Rt. 9999 Alternative No. 3 of 3

Improvement Project(s) Included as Part of this Alternative: Alt. C

1. Flatten curve to 5 degrees 2. Add 300-Ft spirals
3. Widen lanes to 12 Ft 4. Add 8-Ft paved shoulders
5. Flatten sideslope to 6:1 6. Remove 70 trees

Step 1 - Determine Cost for Curve Flattening.

Degree of curve before flattening = 10 after flattening = 5
Central angle = 30

Estimated cost for flattening (from table 8) = $ 212,900

Step 2 - Estimate the Additional Cost for Adding Spirals.

Length of each spiral (from AASHTO Greenbook) = 300
Estimated cost for adding spiral = $ 0

Step 3 - Determine the Added Cost for Upgrading Superelevation.

Cost for superelevation upgrading = $ N.A.

Step 4 - Compute Cost for Lane and Shoulder Widening.

Curve Length (L) = .1136 mi

| | Column A | Column B | Column C |
|---|---|---|---|
| Type of Widening | Amount of Widening in ft (Each Side) | Cost per foot (From table 9) | Column A x Column B |
| Lane | 2 | $ 50,000 | $ 100,000 |
| Paved Shoulder | 8 | $ 23,750 | $ 190,000 |
| Unpaved Shoulder | 0 | — | — |
| $C_M$ = Total Cost of Lane and Shoulder Improvements Per Mi = (Sum Values in Column C) | | | $ 290,000 |

Cost for Lane and Shoulder Improvements for the Curve Length =

$C_{LS} = C_M \times L$ = $ 290,000 x .1136 mi = $ 32,940

FORM C - CURVE IMPROVEMENT COSTS (Continued) *Alt. C*

Step 5 - Determine Cost for Roadside Improvements

Roadside Improvement = Remove 70 trees

Flatten sideslope from 2:1 to 6:1

Cost for obstacle improvements (from table 10 and/or 11) = $ 15,400 = $C_{R1}$

Sideslope before condition = 2:1 After condition = 6:1

Height of fill = 4 ft

Cost for Sideslope flattening =

Cost per mi (from table 12) x (curve length) (No. of sides to be flattened) = $75,100 x .1136 x 2 = $17,060 = $C_{R2}$

Total Cost for Roadside Improvements = $C_{R1} + C_{R2}$

= $15,400 + $17,060 = $32,460

Step 6 - Compute Total Cost of This Alternative

CT = Cost for [Step 1 = $212,900] + [Step 2 = $0] + [Step 3 = $0]

+ [Step 4 = $32,940] + [Step 5 = $32,460] = $ 278,300 = $C_T$

Step 7 - Compute the Annualized Cost

Annualized Cost = $C_A = C_T$ x CRF

= $ 278,300 x .0872 = $24,270

where CRF = Capital Recovery Factor (from table 13) based

service life (= 20) and interest rate (= 6%)

HORIZONTAL CURVE

FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are Being Considered at the Same Location)

STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio

| | Column A | Column B | Column C | Column D | Column E | Column F | Column G | Column H |
|---|---|---|---|---|---|---|---|---|
| Rank | Improvement Number | Annual Benefits (B) | Annual Costs (C) | B/C Ratio | Compare | Incremental Change in Benefits ( B) | Incremental Change in Costs ( C) | Incremental Benefit/ Cost Ratio B/ C |
| Lowest Cost (CT) | B | 27,140 | 4,117 | 6.6 | B+A | $15,340 | $17,703 | .87 (Pick B) |
| 2nd Lowest Cost | A | 42,480 | 21,820 | 1.95 | | | | |
| 3rd Lowest Cost | C | 46,020 | 24,270 | 1.90 | B+C | $18,880 | $20,153 | .94 (Pick B) |
| 4th Lowest Cost | | | | | | | | |
| Highest Cost | | | | | | | | |

STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ( B/ C)

Complete Columns E, F, G. and H in step 1.

STEP 3 - Evaluate Available Funding and Other Agency Constraints

Select improvement with the highest incremental benefits to highest incremental costs:

Improvement No. and Description: B - Widen lanes to 12 Ft, Add 6 Ft paved shoulders, Flatten sideslope to 6:1, and Remove 50 trees

Improvement Cost: $ 4,117 per year

Is funding available to complete project (Yes or No) Yes

Do any other agency constraints prohibit implementation (Yes or No) No

If Yes, Describe: N.A.

Will all curve design guidelines meet with each project alternative? Yes

If not, give details N.A.

FORM D - COMPARISON OF PROJECT ALTERNATIVES (Continued)

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

Improvement No. and Description: N.A.

Improvement Cost: $ N.A. per year

STEP 4 - Record Project Details

Selected Improvement: Alt. B

Project Cost: $ 4,117 per year

Total Project Cost: $ 47,210

Change in Annual Maintenance Costs: $ 0

Accidents Reduced per Year: .46

Annual Accident Benefits: $ 27,140

B/C Ratio = 6.6

Comments:

# APPENDIX A -

# BLANK DATA FORMS A, B, C, AND D

(These forms should be copied and used for conducting an economic analysis of alternative curve improvements)

HORIZONTAL CURVE DESIGN

FORM A - CURVE SITE DESCRIPTION

1. Road Name or Route Identification: ____________________

2. Curve Milepoint Beginning: ______ Ending: ______ Length: ______ (Mi)

3. Area Type (Check): ______ Rural ______ (Ft)

______ Urban (If urban, procedures in this manual do not apply.)

To convert curve radius (R) to Degrees (D):

$$D = \frac{5729.6}{R}$$

4. Degree of curve: ______ (Degrees/100 ft of Arc)

5. Central Angle: ______ (Degrees)

6. Spiral Transitions on Curve Approaches

______ Yes ______ No

7. Actual Superelevation on Curve ($e_A$): ______

8. State Superelevation Policy (check one): ___ .06 ___ .08 ___ .10

9. Roadway Design Speed: ______ mi/h

10. AASHTO Greenbook Recommended Superelevation for this Curve: ______ ($e_R$)

11. Superelevation Deviation ($e_R$ - $e_A$): ______

12. Length of Tangent on Curve Approach: Direction 1: ______ Ft

Direction 2: ______ Ft

13. Terrain Condition (Check One):

______ Flat ______ Rolling ______ Mountainous

14. Present Average Daily Traffic ($ADT_B$): ______

15. Expected Annual Traffic Growth Rate = g = ______ percent per year

16. Lane Width: ______ Ft

17. Paved Shoulder Width: ______ Ft

18. Unpaved Shoulder (e.g., Dirt, Gravel, Turf, Stabilized)

Width = ______ Ft

FORM A - CURVE SITE DESCRIPTION (Continued)

19. Typical Sideslope (Check One):

__2:1, or steeper, __3:1, __4:1, __5:1, __6:1, __7:1 or flatter

20. Average Roadside Recovery Distance = ______ Ft

21. Reliable Accident Data for the Section (Check One):

__________ Available __________ Unavailable

Note: If reliable accident data are unavailable, or if no accidents have been reported at the curve in recent years, economic analysis procedures are not approximate. Review step 5A in text and chapter 2 for improvement guidelines to existing curves.

22. Total Curve Accidents = ________ for ________ years

23. Total Curve Accidents per Year Before Improvement = $A_{TB}$

$$= \frac{\text{Total Number of Curve Accidents}}{\text{Number of Years of Data}}$$

= ________ ÷ ________ = _________

24. (Optional Information): Number of Curve Accidents by Type for _____ Years

Single Vehicle (Run-Off-Road and Rollover) = ______, or ______ Per Year

Head-On and Opposite Direction Sideswipe = ______, or ______ Per Year

Nighttime Accidents = ______, or ______ Per Year

Wet-Weather Accidents = ______, or ______ Per Year

HORIZONTAL CURVE DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Curve Location ______________________________ Alternative ___ of ___

Step 1: Complete the Curve Site Description Form

Step 2: Complete the Following Information on the Proposed Improvement:

Description of Alternative ____________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

| Roadway Feature | Before Treatment | After Treatment |
|---|---|---|
| Degree of Curve | ________ | ________ |
| Spiral Transitions (yes or no) | ________ | ________ |
| Superelevation | ________ | ________ |
| Superelevation Deviation | ________ | ________ |
| Lane Width | ________ | ________ |
| Paved Shoulder Width | ________ | ________ |
| Unpaved Shoulder Width | ________ | ________ |
| Avg. Roadside Recovery Distance | ________ | ________ |
| Typical Sideslope | ________ | ________ |

Step 3: Compute the ADT Over the Future Project Life ($ADT_F$)

ADT before improvement = ______________ = $ADT_B$

Project service life = __________ years

Annual growth rate = g = ________ percent per year

Adjustment factor = _________ = $F_A$ (from table 1)

Future ADT = $ADT_F = (ADT_B) \times (F_A)$ = _____ x _____ = _____

Step 4: Determine the Expected Number of Future Accidents per Year on the Curve Without the Improvement ($A_{UF}$)

- Step 4A: If reliable accident data are unavailable for the curve site or if no accidents have been reported at the curve in recent years, an economic analysis of project alternatives is not feasible. Do not continue past step 4, but refer to chapter 2 for guidelines on making safety improvements.

- Step 4B: Reliable accident data are available for the curve site.

  $A_{TB}$ = ________ Total accidents on the curve per year before treatment (from Form A)

  Service life = ________

  Traffic growth rate = g = ________

  $F_A$ = The factor (from table 1) to adjust current ADT to future ADT
  = ________

  $A_{UF}$ = Future accidents per year in the untreated condition

  = $A_{TB}$ x $F_A$ = ____ x ____ = ____

Step 5: Determine the Accident Reduction (AR) Factor

| Curve Improvement | Source of AR Factor |
|---|---|
| 1. Curve flattening | Table 2 |
| 2. Upgrading deficient superelevation | Table 3 |
| 3. Adding a spiral transition | Use AR factor of 5 percent for adding spirals to curve |
| 4. Lane widening | Table 4 |
| 5. Widening paved shoulder | Table 4 |
| 6. Widening unpaved shoulder | Table 4 |
| 7. Sideslope flattening | Table 5 |
| 8. Removal of roadside obstacles | Table 6 |
| 9. Combining two or more of the improvements into one project | (see Step 5B) |

Note: Pavement resurfacing is assumed to be included with improvements 1 through 6 above.

- Step 5A: Determine AR factors for individual improvement projects using tables 2 through 6, as listed above
  - Curve flattening (use table 2): AR = _____
  - Upgrade superelevation: AR = _____
  - Add spiral (use table 3): AR = _____
  - Lane widening only (use table 4): AR = _____
  - Shoulder widening only (use table 4): AR = _____
  - Roadside improvements (use tables 5 and/or 6): AR = _____

(Note: If curve flattening plus other roadside improvements are proposed for the same alternative, use table 6 for estimating the combined effects of roadside improvements.)

- Step 5B: Combine Individual AR Factors

Overall accident reduction (AR) from more than one improvement:

$$AR = 1 - (1 - AR_1)\ (1 - AR_2)\ (1 - AR_3)\ (1 - AR_4)\ (1 - AR_5)\ .....$$
$$= 1 - (1 - \_\_\_)\ (1 - \_\_\_)\ (1 - \_\_\_)\ (1 - \_\_\_)\ (1 - \_\_\_) = \_\_\_\_\_$$

where:

$AR_1$, $AR_2$ and $AR_3$, etc. are accident reduction factors for improvements 1, 2, 3, etc., respectively

Step 6: Compute the Estimated Number of Annual Accidents Reduced ($\Delta A$)
The net number of total curve accidents reduced per year ($\Delta A$) is computed as follows:

$$\Delta A = (A_{UF}) \times (AR)$$

where:

$A_{UF}$ = future accidents per year in the untreated condition (from step 4B)

AR = combined accident reduction factor (from step 5B).

Thus, $\Delta A = A_{UF} \times AR = \_\_\_\_ \times \_\_\_\_ = \_\_\_\_\_$ accidents reduced per year

Step 7: Determine the Average Cost per Curve Accident ($C_A$)

$C_A$ = $_______ (Use $59,000 if unknown)

Step 8: Compute the Expected Annual Accident Benefits ($B_A$)

$B_A$ = accident benefits per year based on the net reduction in curve accidents

$$(\Delta A) \times (C_A) = \_\_\_\_\_ \times \$\_\_\_\_\_\_\_\_ = \$\_\_\_\_\_\_\_\_\_$$

where,

$\Delta A$ = net reduction in accidents per year (see step 6)

$C_A$ = average cost of a curve accident (see step 7)

## HORIZONTAL CURVE DESIGN

## FORM C - CURVE IMPROVEMENT COSTS

(Complete One of These Forms for <u>Each</u> Project Alternative)

Curve Location ____________________ Alternative No. ____ of ____

Improvement Project(s) Included as Part of this Alternative:

1.____________________ 2. ____________________

3.____________________ 4. ____________________

5.____________________ 6. ____________________

Step 1 - Determine Cost for Curve Flattening.

Degree of curve before flattening = ______ after flattening = ______
Central angle = ______

Estimated cost for flattening (from table 8) = $__________

Step 2 - Estimate the Additional Cost for Adding Spirals.

Length of each spiral (from AASHTO Greenbook) = __________
Estimated cost for adding spiral = $__________

Step 3 - Determine the Added Cost for Upgrading Superelevation.

Cost for superelevation upgrading = $__________

Step 4 - Compute Cost for Lane and Shoulder Widening.

Curve Length (L) = ________ mi

| Type of Widening | Column A<br>Amount of Widening in ft (Each Side) | Column B<br>Cost per foot (From table 9) | Column C<br>Column A x Column B |
|---|---|---|---|
| Lane | ____ | ______ | ______ |
| Paved Shoulder | ____ | ______ | ______ |
| Unpaved Shoulder | ____ | ______ | ______ |
| $C_M$ = Total Cost of Lane and Shoulder Improvements Per Mi = (Sum Values in Column C) | | | ______ |

Cost for Lane and Shoulder Improvements for the Curve Length =

$C_{LS} = C_M \times L$ = $________ x ________mi = $__________

Step 5 - Determine Cost for Roadside Improvements

Roadside Improvement = ______________________________

______________________________

Cost for obstacle improvements (from table 10 and/or 11) = $______ $= C_{R1}$

Sideslope before condition = ______ After condition = ______

Height of fill = ______ ft

Cost for Sideslope flattening =

Cost per mi (from table 12) x (curve length) (No. of sides to be flattened) = ________ x ________ x ________ = ________ $= C_{R2}$

Total Cost for Roadside Improvements $= C_{R1} + C_{R2}$

= ________ + ________ = ________

Step 6 - Compute Total Cost of This Alternative

CT = Cost for [Step 1 =________] + [Step 2 =________] + [Step 3 =________]

+ [Step 4 =________] + [Step 5 =________] = $__________ $= C_T$

Step 7 - Compute the Annualized Cost

Annualized Cost $= C_A = C_T \times CRF$

= $__________ x __________ = __________

where CRF = Capital Recovery Factor (from table 13) based service life (=________) and interest rate (= ________)

HORIZONTAL CURVE

FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are Being Considered at the Same Location)

STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio

| | Column A | Column B | Column C | Column D | Column E | Column F | Column G | Column H |
|---|---|---|---|---|---|---|---|---|
| Rank | Improvement Number | Annual Benefits (B) | Annual Costs (C) | B/C Ratio | Compare | Incremental Change in Benefits ( B) | Incremental Change in Costs ( C) | Incremental Benefit/ Cost Ratio B/ C |
| Lowest Cost (CT) | | | | | | | | |
| 2nd Lowest Cost | | | | | | | | |
| 3rd Lowest Cost | | | | | | | | |
| 4th Lowest Cost | | | | | | | | |
| Highest Cost | | | | | | | | |

STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)

Complete Columns E, F, G. and H in step 1.

STEP 3 - Evaluate Available Funding and Other Agency Constraints

Select improvement with the highest incremental benefits to highest incremental costs:

Improvement No. and Description: ____________________

____________________

____________________

Improvement Cost: $__________ per year

Is funding available to complete project (Yes or No) ________

Do any other agency constraints prohibit implementation (Yes or No)

________

If Yes, Describe: ____________________

Will all curve design guidelines meet with each project alternative?

________

If not, give details ____________________

____________________

FORM D - COMPARISON OF PROJECT ALTERNATIVES (Continued)

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

Improvement No. and Description: ______________________________

Improvement Cost: $_________________ per year

STEP 4 - Record Project Details

Selected Improvement: ________________________________________

Project Cost: $_________________ per year

Total Project Cost: $_________________

Change in Annual Maintenance Costs: $_________________

Accidents Reduced per Year: ____________________

Annual Accident Benefits: $__________________

B/C Ratio = _____________

Comments: ___________________________________________________

_____________________________________________________________

_____________________________________________________________

_____________________________________________________________

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